

STANDARD OPERATING PROCEDURES

VOLUME III OF VI GEOTECHNICAL

**ROCKY FLATS PLANT
ENVIRONMENTAL MONITORING AND ASSESSMENT DIVISION
P.O. Box 464
Golden, CO 80402**

February 1991

A-SW-000142

REVIEWED FOR CLASSIFICATION/UCM

By V. A. Muenchow *(unw)*

Date 6/11/91

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TITLE:

LOGGING ALLUVIAL AND
BEDROCK MATERIAL

Approved By:

J. W. Langmaier

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) is part of the Rocky Flats Environmental Restoration (ER) Program Sampling Analysis Plan (SAP). The SAP includes the Quality Assurance Project Plan (QAPjP) and SOPs, which are program-wide documents that are not project-specific. These program-wide documents have been reviewed and approved by the Environmental Protection Agency (EPA) and the Colorado Department of Health (CDH) for ER activities at Rocky Flats.

Project-specific requirements are described in individual project work plans that include a Field Sampling Plan (FSP). The FSP will include or reference the applicable program SOPs. Procedural details not covered by the program-wide SOPs will be provided in SOP addenda (SOPAs). In general, an SOPA will conform with the original SOP but will be project-specific. The SOPAs will be an attachment to the FSP and must accompany the FSP and SOPs during field operations.

The project-specific SOPAs, if required, will be prepared by the subcontractor designated to prepare the work plans.

Over the period of the last few years, it has become apparent that a standardized procedure is needed for logging alluvial and bedrock material. This need has arisen because each subcontractor has slightly different procedures and criteria for logging borehole material. Beginning in 1991, all subcontractors will use the procedures that are covered in this SOP.

By applying these techniques and procedures, it will be possible to standardize the logging of alluvial and bedrock materials. In addition, the number of errors and the amount of relogging will be reduced. This will allow lithologic descriptions to be compared from year to year and will enable the environmental restoration staff on the Rocky Flats Plant (RFP) site to make interpretations based on reliable data.

On the RFP site, "alluvial material" includes alluvium, colluvium, fill, and agronomic soils. Samples of alluvium, colluvium, fill, and agronomic soils are to be classified and described using the Unified Soil Classification System (U.S.C.S.) and enhanced by Item 10.1 in ASTM D2488, "Description and Identification of Soils (Visual-Manual Procedure)." Bedrock material, regardless of the degree of weathering, is to be classified and described by using many of the procedures and techniques described in Compton's "Manual of Field Geology" (1962) and additional material covered in this SOP.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

The EG&G project manager has the overall responsibility for implementing this SOP. The subcontractor's project manager will be responsible for assigning project staff to implement this SOP and for ensuring that the procedures are followed by all subcontractor personnel.

All personnel performing these procedures are required to have the appropriate health and safety training as specified in the site-specific Health & Safety Plan. In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures, if necessary.

Only qualified personnel will be allowed to perform these procedures. Required qualifications vary depending on the activity to be performed. In general, qualifications are based on education, previous experience, on-the-job training, and supervision by qualified personnel. Personnel who log alluvial boreholes must study the RFP Alluvial Reference Set that contains examples of all 15 sample classifications within the U.S.C.S. System. Personnel who log bedrock boreholes must be qualified geologists or geologic engineers, who have received special permission to log bedrock holes. All of the loggers must study the Core Reference Set that contains 15 representative samples of the stratigraphic section in the RFP area. In addition they must also study the Alluvial

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Reference Set. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project Quality Assurance (QA) files.

All project staff are responsible for reporting deviations from this SOP to the individual's project manager. The subcontractor's project manager will report deviations and nonconformances to the EG&G project manager.

When field conditions require deviations from the SOP or SOPA, a Procedural Deviation Notice (PDN) will be authorized by an EG&G EMAD logging supervisor. An EG&G ER Department Administrative Procedure outlines the PDN approval process.

4.0 REFERENCES

4.1 SOURCE REFERENCES

ASTM. Method for Particle - Size Analysis of Soils; Soil and Rock Dimensions, Stone and Geo-Synthetics. Vol. 04.08. Sec. D422. 1989.

ASTM. Practice for Description and Identification of Soils for Engineering Purposes (Visual-Manual Procedures); Soil and Rock Dimensions, Stone and Geo-Synthetics. Vol. 04.08. Sec. D2488. 1989.

Blatt, H., Middleton, G., Murray, R. Origin of Sedimentary Rocks. Prentice-Hall. 1972.
Compton, Robert R. Manual of Field Geology. John Wiley & Sons, Inc. 1962.

Harlan, R.L., Kolm, K.E., Gutentag, E. D. Water-Well Design and Construction. Development in Geotechnical Engineering, #60. Elsevier. 1989.

Krumbein, W.C., Pettijohn, F.J. Manual of Sedimentary Petrography. Appleton-Century-Crofts. 1966.

Unified Soil Classification System. Appendix A: Characteristics of Soil Groups Pertaining to Embankments and Foundations, Appendix B: Characteristics of Soil Groups Pertaining to Roads and Airfields. (U.S.) Army Engineer Waterways Experiment Station. Vicksburg, MS. 1960.

5.0 CLASSIFICATION/DESCRIPTION

5.1 UNIFIED SOIL CLASSIFICATION SYSTEM (U.S.C.S)

The U.S.C.S., as used in this SOP, has been modified from the Army Corps of Engineers' Technical Memorandum No. 3-357, "The Unified Soil Classification System" (1960). The liquid limit, dilatancy, and dry strength are not included because they are neither practical to do in the field nor applicable to hydrogeologic logging. A reprint of the U.S.C.S. is enclosed in Appendix A.

5.1.1 Basis of Classification

The U.S.C.S. historically has been used to classify "soils" based on their textural properties, liquid limit, and organic content. In the past the term "soil" has been used by engineers as a catchall term that includes all unconsolidated material. Because engineers are concerned with how the soil behaves as a construction material, this all-inclusive approach has served them quite well.

However, in this SOP, the U.S.C.S. will be applied only to alluvium, colluvium, fill, and agronomic soils. This has been done to separate unconsolidated cover material from bedrock that has well-defined sedimentologic and depositional patterns, regardless of the degree to which the bedrock has been weathered. In the RFP area, it is more important to determine the possible paths of

groundwater movement based on geologic processes than it is to determine the engineering properties of weathered bedrock based on its physical behavior.

5.1.2 Texture

5.1.2.1 Grain Size Scale

The U.S.C.S. has a grain size scale that is divided into four main categories: (1) cobbles, (2) gravel, (3) sand, and (4) fines. The gravel, sand, and fines are subdivided into coarse and fine gravel; coarse, medium, and fine sand; and silt and clay.

Table 3.1-1 is a summary of the U.S.C.S. grain size scale as well as the Wentworth, Atterberg, and U.S. Department of Agriculture grain size scales (Krumbein and Pettijohn 1966; and Compton 1962).

Neither the U.S.C.S. nor the U.S. Department of Agriculture grain size scales have a common base. However, both the Wentworth and the Atterberg grain size scales are geometric series with a base of 2 and 10, respectively.

Finally, it should be noted that the division between sand and silt varies from scale to scale. This makes it somewhat difficult to compare the U.S.C.S. grain size analyses with analyses based on other scales. Most geotechnical laboratories show only the U.S.C.S. grain size ranges on the graph paper. Figure 3.1-1 is a modified graph that shows both the U.S.C.S. and Wentworth grain size ranges. ASTM D422, "Particle-Size Analysis of Soils," should be used to perform the grain size analyses but should be modified to include a 230 sieve.

TABLE 3.1-1

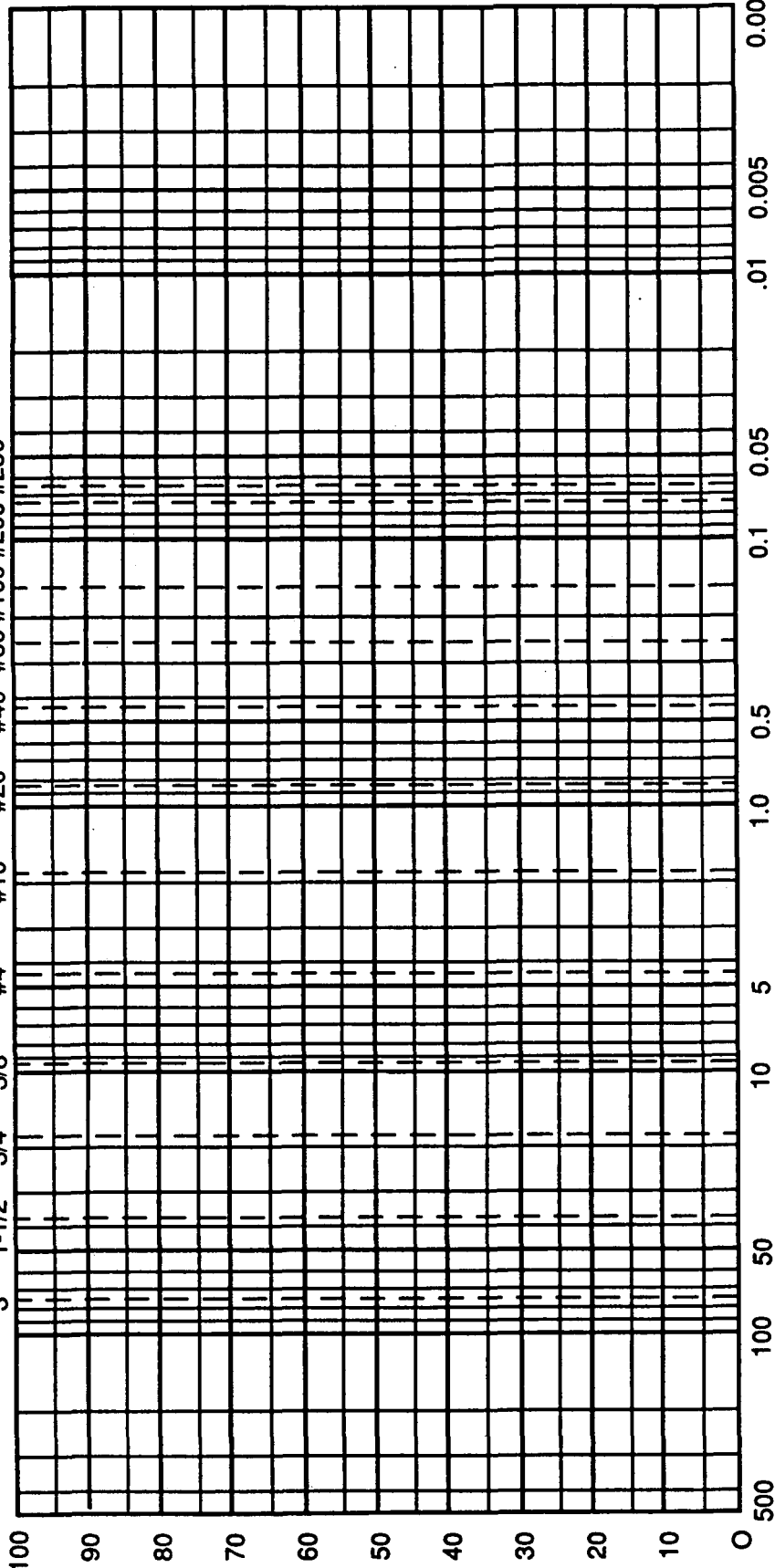
Grain Size Scales (millimeter[mm])

<u>U.S.C.S.</u>	<u>Wentworth</u>	<u>Atterberg</u>	<u>U.S. Dept. Ag.</u>	<u>Component</u>
> 76.2	256-64	200-20	> 80	Cobbles
--	64-32*	--	--	V.C. Gravel
76.2-19	32-16*	--	--	C. Gravel
--	16-8*	20-2*	80-2	M. Gravel
19-4.76	8-4*	--	--	F. Gravel
--	4-2	--	--	Granule
--	2-1	--	2-1	V.C. Sand
4.76-2	1-0.5	2-0.2	1-0.5	C. Sand
2-.42	0.5-0.25	--	0.5-0.25	M. Sand
.42-.074	0.25-0.125	0.2-0.02	0.25-0.1	F. Sand
--	0.125-0.0625	--	0.1-0.05	V.F. Sand
<.074	0.0625-0.0039	0.02-0.002	0.05-0.002	Silt
--	<0.0039	<0.002	<.002	Clay
Variable	Base 2	Base 10	Variable	
*Pebbles				



U.S. STANDARD SIEVE SIZE

3" 1-1/2" 3/4" 3/8" #4 #10 #20 #40 #60 #100 #200 #230



PERCENT COARSER BY WEIGHT

PERCENT FINER BY WEIGHT

0 10 20 30 40 50 60 70 80 90 100 500 100 50 10 5 1.0 0.5 0.1 0.05 .01 0.005 0.001

GRAIN SIZE IN MILLIMETERS

USCS	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

WENTWORTH	PEBBLE GRAVEL			SAND			SILT	CLAY
	COARSE	MED	FINE	COARSE	MED	FINE		

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FIGURE 3.1-1

WELLNAME: _____

SAMPLE NO.: _____

DATE: _____

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DIRK 800004 FILE #VEB32

AREA	DEPTH	CLASSIFICATION

It is important to mention that a degree of error is inherent between all versions of grain size estimates made in the field and those that are made in the laboratory. The field data are based on volumetric (visual) estimates while the laboratory data are derived from weight measurements. In addition, it must be stressed that sieves and grain size charts should be used regularly whenever estimates are being made.

5.1.2.2 Graded Material

The concept of graded material is used to describe the number of grain size ranges that are present within the central portion (approximately 80 percent) of the grain size distribution for samples with less than 5 percent fines (silt and clay). If a sample contains predominantly one or two grain-size ranges (such as medium and fine sand), it is poorly graded and has a symbol (P). If a sample contains several grain size ranges (such as fine gravel, coarse sand, medium sand, and fine sand), it is well graded and has a symbol (W).

Field values may be checked after the grain size analyses have been calculated and plotted. The uniformity coefficient is a useful value that may help determine whether a gravel or a sand is well graded. The formula for the uniformity coefficient is:

$$U_c = D_{60}/D_{10}$$

where the D values are read directly from the grain size plots and represent the amount of material that is finer by weight. Well-graded gravels have a value greater than 4, and well-graded sands have a value greater than 6.

5.1.3 Field Estimates of Plasticity

The plasticity characteristics of fine-grained alluvium or the fine fraction of a coarse alluvium should be determined per the procedures covered in the U.S.C.S. (Appendix A). The following paragraph and paragraph excerpts are taken from the U.S.C.S in Appendix A:

"Particles larger than about the No. 40 sieve size are removed (by hand), and a specimen of soil about the size of a 1/2-inch cube is molded to the consistency of putty. If the soil is too dry, water must be added, and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. The sample is rolled by hand on a smooth surface or between the palms into a thread about 1/8 inches in diameter. The thread is then folded and rerolled repeatedly. During this manipulation, the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. The higher the position of the soil above the 'A' line on the plasticity chart. . . the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the soil is remolded after rolling."

5.1.3.1 Low Plasticity

Alluvial samples with a low plasticity "form a weak thread and . . . cannot be lumped together into a coherent mass below the plastic limit."

5.1.3.2 Medium Plasticity

Alluvial samples with a medium plasticity "form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily."

5.1.3.3 High Plasticity

Alluvial samples with a high plasticity form a stiff thread "as their water content approaches the plastic limit and the tougher are the lumps as the soil is remolded after rolling."

5.1.4 U.S.C.S. Sample Classification

The sample classifications of the U.S.C.S. are illustrated in Figure 3.1-2. In order to classify alluvium, colluvium, fill, and agronomic soils, it is necessary first to estimate the percent of all the grain size ranges in the sample and determine the plasticity of the fines if they comprise more than 50 percent of the sample. With this information, enter Figure 3.1-2 from the left and progress to the right matching the textural, plasticity, and organic characteristics of the sample.

The progression through Figure 3.1-2 is an "if/then" sequence of decisions that ultimately leads to the proper sample classification. Two examples follow:

- **Example 1:** Seventy-five percent of the material is greater than the No. 200 sieve; 53 percent greater than the No. 4 sieve (gravel); 22 percent is sand; and 25 percent is fines (10 percent silt and 15 percent clay). The proper classification for this sample is a clayey gravel with some silt and sand (GC).
- **Example 2:** Eighty-five percent of the material is smaller than the No. 200 sieve; 5 percent is gravel; 10 percent is sand; 30 percent is silt; and 55 percent is clay that has a low to medium plasticity. The proper classification for this sample is a silty clay with a trace of gravel and some sand (CL).

SOIL TYPES

Major Divisions			Letter	Symbol	Description
Coarse Grained Soils	Gravel and Gravely Soils	Clean Gravels ($< 5\%$ fines)	GW		Well graded gravels or gravel-sand mixtures, little or no fines. Uc > 4 (lab only)
			GP		Poorly graded gravels or gravel-sand mixtures, little or no fines.
		Gravels with Fines ($> 12\%$ fines)	GM		Silty gravels, gravel-sand-silt mixtures.
			GC		Clayey gravels, gravel-sand-clay mixtures.
	Sand and Sandy Soils	Clean Sand ($< 5\%$ fines)	SW		Well-graded sands or gravelly sands, little or no fines. Uc > 6 (lab only)
			SP		Poorly-graded sands or gravelly sands, little or no fines.
		Sands with Fines ($> 12\%$ fines)	SM		Silty sands, sand-silt mixtures.
			SC		Clayey sands, sand-clay mixtures.
Fine Grained Soils	Sils and Clays	Low Plasticity	ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
			OL		Organic silts and organic silty clays of low plasticity
		High Plasticity	MH		Inorganic silts, micaceous or diatomaceous fine sand or silty soils
			CH		Inorganic clays of high plasticity, fat clays
			OH		Organic clays of medium to high plasticity, organic silts
		Highly Organic Soils		PT	

Note: Dual Symbols are used to indicate borderline soil classifications whose fines range from 5 to 12%.

DAK 300004 FILE SOIL TYPE

Unified Soil Classification System

FIGURE 3.1-2

Modified from "Water-Well Design and Construction; Development in Geotechnical Engineering, 60," by R.L. Harlan, K.E. Koln and E.D. Gutentag; Elsevier, 1989.

Sample descriptions should be made in the following order:

- Main textural classification with modifiers
- Color
- Grain size
- Grading
- Angularity (ASTM D2488)
- Plasticity
- Composition
- Bedding
- Moisture content
- Top of bedrock, if present

5.1.5 Problems With the U.S.C.S.

The following are problems that are intrinsic to the U.S.C.S. An obvious problem with the U.S.C.S. is that a change of one or two percent in coarse or fine material on either side of the 50 percent boundary may cause the sample classification to vary considerably. For example, a clayey gravel (GC) or a clayey sand (SC) could easily change to a gravelly clay or a sandy clay with low plasticity (CL) or a sandy clay with high plasticity (CH). Clearly a classification system that is this sensitive is subject to errors, especially in the field.

Another problem is that it is all but impossible to determine a liquid limit in the field. For the purposes of this SOP, the liquid limit has been replaced by field estimate of plasticity (see Subsection 5.1.3).

The U.S.C.S. also lacks the textural property of angularity that helps to determine the maturity of a sediment.

Finally the U.S.C.S. is a purely descriptive classification that has been designed for construction purposes and concentrates heavily on the physical properties of clay. Because of this, the U.S.C.S. has 15 sample classifications and is very cumbersome.

5.2 BEDROCK DESCRIPTIONS

All bedrock material should be classified and described by using the procedures and techniques described in Compton (1962) and additional material covered in this SOP.

5.2.1 Basis of Classification

Compton classifies sedimentary rocks on the basis of their texture, fabric, and composition. Rock descriptions such as conglomerate, sandstone, siltstone, and shale (claystone and mudstone) are textural classifications based solely on grain size. When other properties like sorting, roundness, bed thickness and contacts, cross-stratification, color, composition, cement, porosity, and fossil content are included, it is possible to make interpretations of where, how, and under what conditions the sediments were deposited.

5.2.2 Textural Parameters

5.2.2.1 Grain Size Scale

The Wentworth grain size scale is divided into six main categories: (1) cobbles, (2) pebbles, (3) granules, (4) sand, (5) silt, and (6) clay. The pebble and sand categories are subdivided into very coarse, coarse, medium, and fine pebbles; and very coarse, coarse, medium, fine, and very fine sand (see Table 3.1-1). The scale is a geometric series with a base of 2.

Unlike the U.S.C.S. in which the sand/silt boundary occurs at 0.074 mm, the sand/silt boundary occurs at 0.0625 mm in the Wentworth scale. Since geotechnical laboratories generally plot grain size analyses on graph paper that is compatible with the U.S.C.S., it is important to ensure that they also include the range of Wentworth grain size intervals on the graph paper (Figure 3.1-1).

5.2.2.2 Degree of Sorting

Sorting is a measure of the extent to which a sediment has been winnowed or reworked during transport. It also is a good indicator of the maturity of a sediment, the energy of the transporting agent, and the environment of disposition.

In order to determine the degree of sorting, Compton (1962) states, "an estimate is made of the range of grain sizes that include the bulk (here 80 percent) of the detrital materials." It is then necessary to count the number of size ranges that are contained in the 80 percent sample (see Table 3.1-1). The number of size ranges is then compared with Figure 3.1-3 to determine the degree of sorting that describes the sample best.

5.2.2.3 Degree of Rounding

Rounding is a measure of the amount of abrasion a grain has undergone. However, it is not generally used to describe sediments that are much finer than sand, because grains finer than sand tend to have elastic collisions that do not affect the shape of the grain. Two properties that must be considered when estimating the degree of rounding are (1) the composition and (2) the original shape of the grain. Rounding, like sorting, is a measure of the maturity of a sediment. The shapes shown in Figure 3.1-4 should be used to estimate the degree of rounding of individual grains.

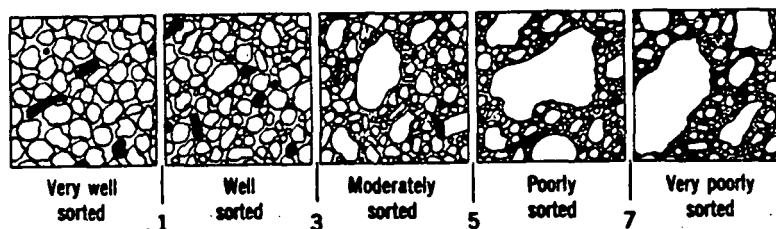


FIGURE 3.1-3

Terms for degrees of sorting. The numbers indicate the number of size-classes included by the great bulk (80 percent) of the material. The drawings represent sandstones as seen with a hand lens. Silt and clay-size materials are shown diagrammatically by the fine stipple. Taken from Compton, 1962.

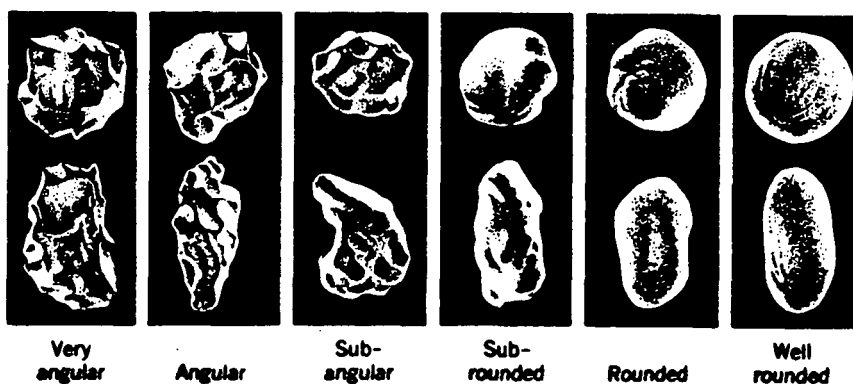


FIGURE 3.1-4

Terms for degree of rounding grains as seen with a hand lens. After Powers, M. C., 1953, "Journal of Sedimentary Petrology", v. 23, p. 118. Courtesy of the Society of Economic Paleontologists and Mineralogists. Taken from Compton, 1962.

5.2.2.4 Porosity

Porosity is not always an easy property to estimate in the field because the bedrock can be drastically altered during drilling and coring as well as by weathering. Generally, samples exhibit more porosity than the rock actually contains.

Porosity should be expressed as a percentage. An accurate estimate is important because the amount of porosity can give a general indication of the permeability of a rock.

5.2.3 Estimate of Abundance

Figure 3.1-5 is composed of several drawings that represent the field of view commonly seen through a microscope or hand lens. Each circle contains a number of black areas. Below each circle is the actual percentage of black area that the circle contains. All loggers should review Figure 3.1-5 until they are adept at estimating the percentages that are contained in the circles.

5.2.3.1 Division of Abundance

Quite often it is necessary to determine the relative abundance of a variable. In these cases, the use of the terms trace, some, and abundant has a utility. The ranges for each are given in Table 3.1-2.

CHARTS FOR ESTIMATING PERCENTAGE COMPOSITION OF ROCKS AND SEDIMENTS

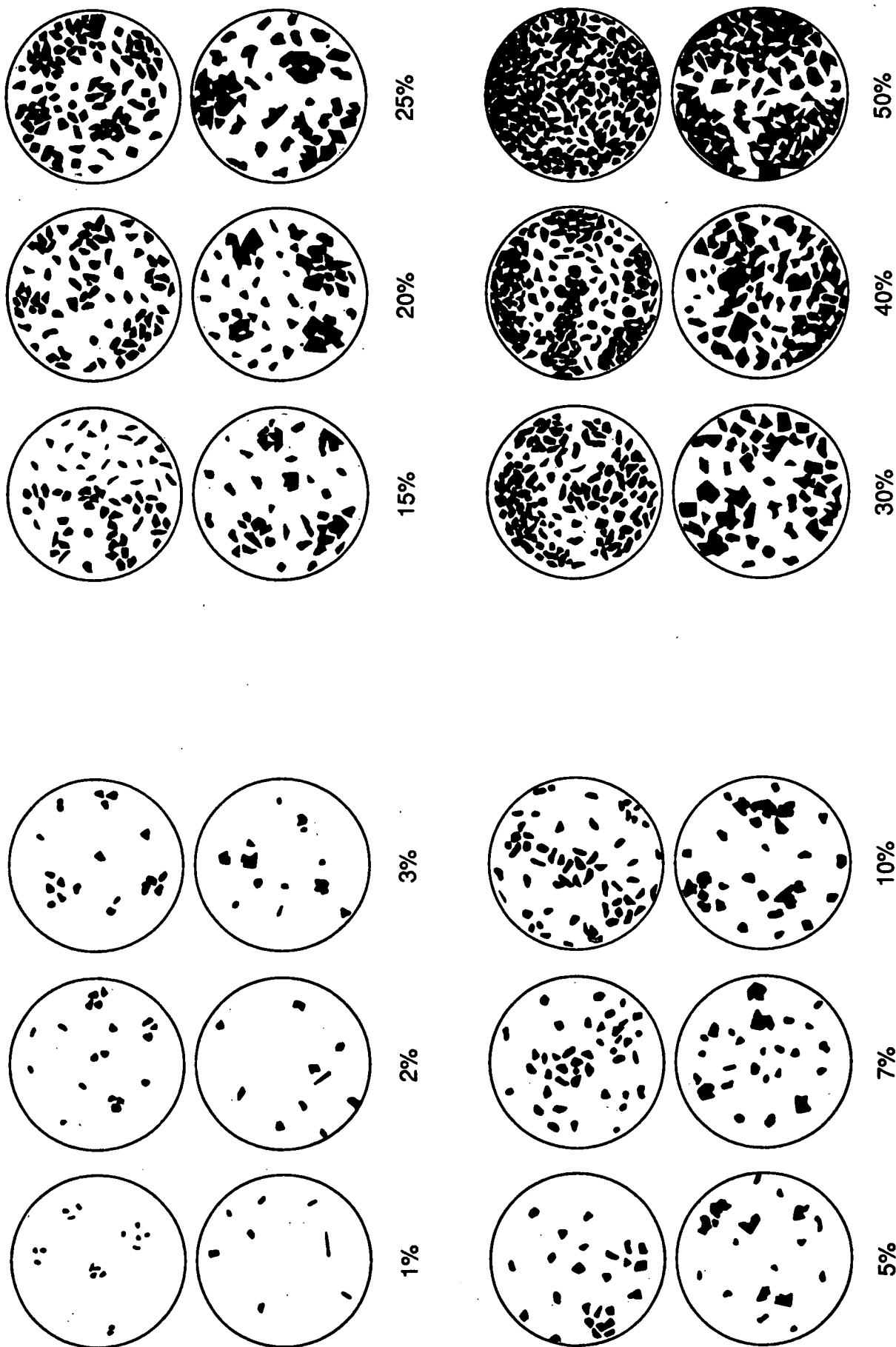


FIGURE 3.1-5

Prepared by R. D. Terry and G. V. Chilingar for "Journal of Sedimentary Petrology" (v. 25, pp. 229-234, 1955); reprinted as "Data Sheet 6" of "Geotimes" available from the American Geological Institute, 2101 Constitution Ave., N.W., Washington, D. C. Reprinted here by permission of the authors and the Society of Economic Paleontologists and Mineralogists. Taken from Compton, 1962.

TABLE 3.1-2
RANGE OF ABUNDANCE

<u>Division</u>	<u>Range of Percent</u>
Trace	>0 to 5
Some	6 to 25
Abundant	26 to 100

These terms generally follow a "with" statement; such as, Sandstone; light olive gray (5Y6/1), very fine to fine grained, with a trace of carbonaceous material.

5.2.4 Color

Color can convey a great deal of information. It helps to identify the components of the sediment or rock as well as the cement. In addition, color can provide a fairly accurate idea of the current chemical environment from which the sample was taken. For example, at RFP, highly weathered (oxidized) sandstones are commonly brownish-orange while unweathered sandstones are light olive grey.

To ensure that the color descriptions are accurate and standardized, each sample should be described while it is wet by using the Geological Society of America "Rock-Color Chart" (1984). If the sample has dried, it should be moistened with clean water from a squirt bottle. Care should also be taken to remove sunglasses when a color determination is being made.

5.2.5 Rock Classification

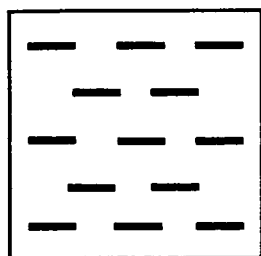
Clastic rocks are primarily classified on the basis of their most frequent grain size. The majority of rocks at RFP are claystone, siltstones, and sandstones; however, hybrids of these end members are quite common. The second and sometimes third most frequent constituents act as modifiers and precede the major rock name in the description; such as, silty sandstone or clayey siltstone. If, however, a rock is composed of 80 percent or more of one constituent, then it should be described solely as that rock type. The secondary textural modifiers should then be described in the description following a "with" statement. Figure 3.1-6 shows all the rock classifications and their lithologic symbols that should be used while logging bedrock samples.

5.2.6 Cement

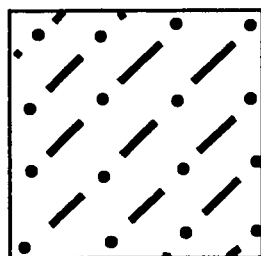
The nature of the cementing medium should be described whenever possible. Typical cementing agents are clay (argillaceous cement), silica, and calcium carbonate (caliche).

5.2.7 Friability

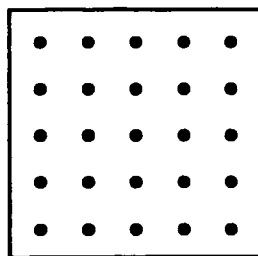
The tendency of a rock to crumble is related to how well it is cemented and the extent to which it has been weathered. Table 3.1-3 shows the degree of friability.



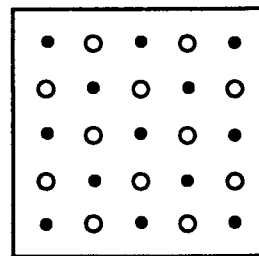
CLAYSTONE



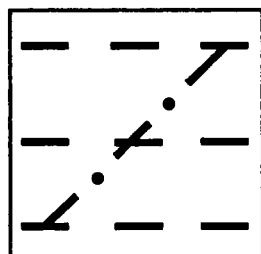
SILTSTONE



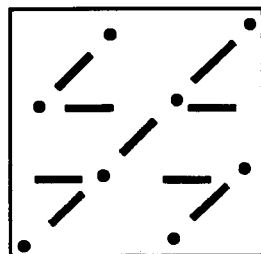
SANDSTONE



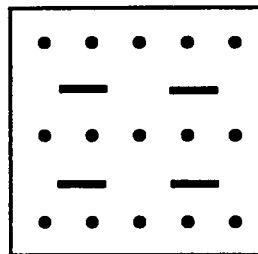
CONGLOMERATE



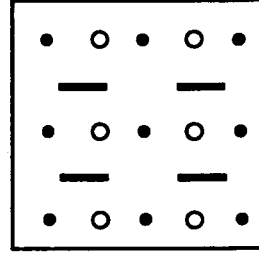
SILTY
CLAYSTONE



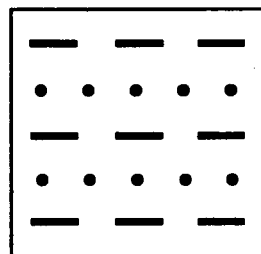
CLAYEY
SILTSTONE



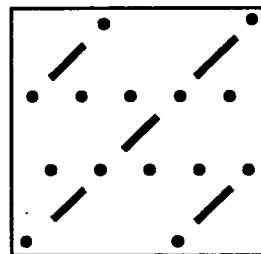
CLAYEY
SANDSTONE



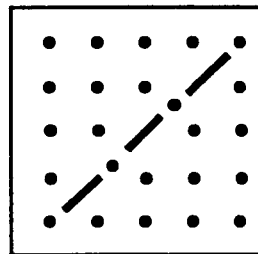
CLAYEY
CONGLOMERATE



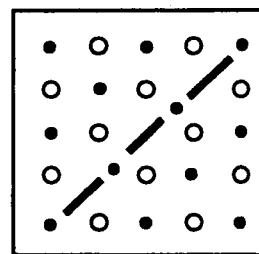
SANDY
CLAYSTONE



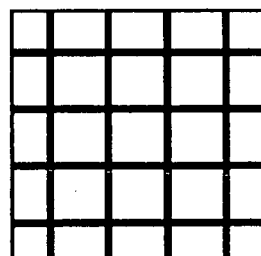
SANDY
SILTSTONE



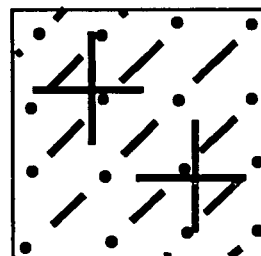
SILTY
SANDSTONE



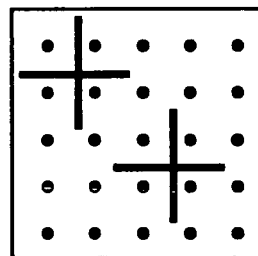
SILTY
CONGLOMERATE



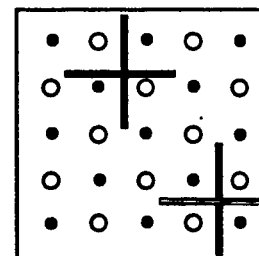
CALICHE



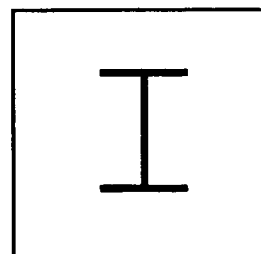
SILTSTONE
w/ CALICHE



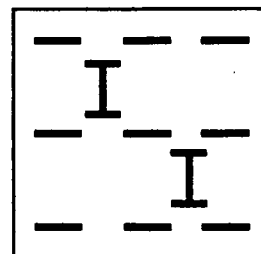
SANDSTONE
w/ CALICHE



CONGLOMERATE
w/ CALICHE



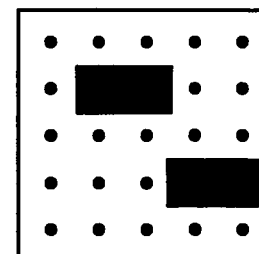
IRONSTONE
or IRONOXIDE
MODULES



CLAYSTONE
w/ IRONOXIDE
MODULES



COAL



SANDSTONE
w/ CARBONACEOUS
MATERIAL

DBK30004 FILE SQUARES

FIGURE 3.1-6 LITHOLOGIC SYMBOLS FOR COMMON CLASTIC ROCKS

TABLE 3.1-3
DEGREE OF FRIABILITY

<u>Term</u>	<u>Definition</u>
Highly Friable	Crumbles readily into individual grains upon minor disturbance
Moderately Friable	Will crumble into individual grains with extensive rubbing
Slightly Friable	Can be broken into individual grains by scraping it with a pocket knife
Non-Friable	Cannot be broken into individual grains by any of the methods described above

5.2.8 Composition

It is not the objective of this SOP to classify sedimentary rocks on the basis of their mineral content by using tertiary diagrams with quartz/chert, feldspar, and lithic fragments at each pole. Since Compton wrote the "Manual of Field Geology" in 1962, several classifications have been published. Two of the most widely used classifications are those published by Earl McBride in 1963 and Robert Folk in 1974. Blatt, et al., (1972) presents an excellent evaluation of these and other classifications. For the purpose of this SOP, the geologist is concerned with describing only accessory minerals, fossils, and other components that distinguish one rock from another. The descriptive term(s) should follow a "with" statement; such as, silty sandstone; light olive grey (5Y6/1), very fine grained, with some pink feldspar rock fragments.

5.2.9 Bedding and Internal Structure

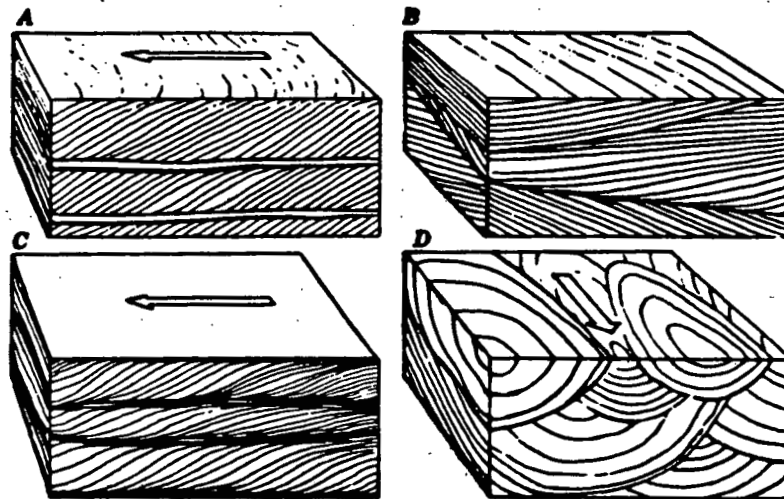
In sedimentary rocks, bedding is related to differences in texture, composition, and color, and reflects changes in the environment of deposition and/or the source material. Depending on the depositional processes that are involved, bedding boundaries may or may not represent a specific moment in time.

Compton classifies bedding as repeated sequences of beds, shapes of individual beds, and cross-bedding (cross-stratification). Repeated bedding is produced by cyclic changes in the sedimentary processes. Individual bed shapes are classified as tabular, lenticular, linear, wedge-shaped, or irregular. Cross-stratification is classified on the basis of its external and internal characteristics. External forms of cross-stratification are tabular, wedge shaped, and trough shaped. Internal descriptive terms that are commonly used are graded, massive, laminated, and tangential (Figure 3.1-7). Other internal features not related to bedding are ripple marks, flow structures, burrows and tubes, load casts, and desiccation cracks (mud cracks).

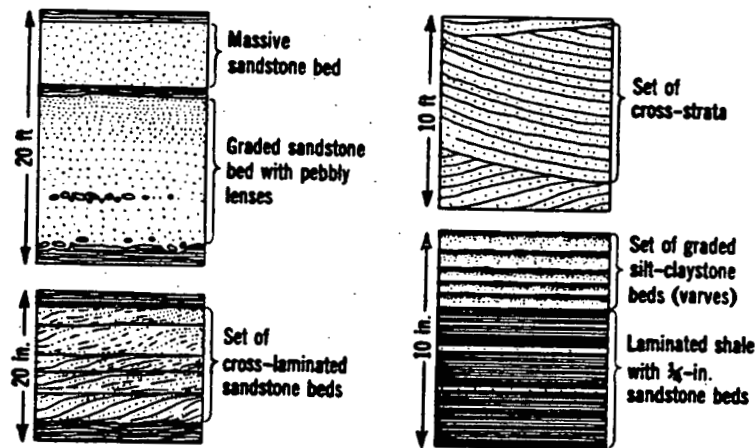
5.2.10 Fractures and Slickensides

Fractures should be described whenever they are present. Fractures occur naturally in bedrocks and should not be confused with breaks induced by coring and handling. The characteristics that should be noted about the fracture are:

- Whether the fracture is opened or healed
- The composition of the material filling the fracture, if any
- The angle of the fracture from the horizontal
- The apparent displacement of bedding across the fracture
- Whether slickensides are present and the angle of any striations from the horizontal



Cross-bedded rocks. (A) Tabular sets with diagonal patterns. (B) Wedge sets, showing considerable erosion between each set. (C) Tabular to lenticular sets with tangential patterns; typically, these are laminated marine beds. (D) Symmetrical trough sets with distinctly linear axes; typically, these are large-scale fluvial features. The arrows indicate current directions. Taken from Compton, 1962.



Various beds and sets of beds. Taken from Compton, 1962.

FIGURE 31-7

5.2.11 Moisture Content

The core should be described as dry, moist, or saturated, and the depth to the top of the saturated interval should be recorded. If a static water level can be measured, it should be noted also.

5.2.12 Lithologic Description

Lithologic descriptions should be made in the following order:

- Main rock type with modifiers
- Color
- Grain size
- Degree of sorting
- Degree of rounding
- Porosity
- Cement
- Friability
- Composition
- Bedding and internal structure
- Fractures and slickensides
- Moisture content
- Top of bedrock, if present

6.0 LOGGING

This section describes the field procedures used while logging.

It is the responsibility of the logging personnel to ensure that all of the materials and equipment needed for logging are at the site.

6.1 LOGGING EQUIPMENT

The following is a list of equipment that is necessary to properly log the alluvial and bedrock material.

- Core Reference Set
- Alluvial Reference Set
- Rock-Color Chart
- Logging forms
- Hand lens
- Nos. 4, 40, 200, and 230 sieves (8-inch) with lid and base
- Six-foot metal measuring tape in tenths of a foot and tenths of an inch
- Core boxes (2 feet long, 5 columns each 2-1/2 inches wide) (such as, Boise Cascade No. 17-505 top and bottom)
- Wood blocks (2-1/2 inches x 3/4 inches) for marking depths and sample locations
- Jars for cuttings
- Wentworth and/or Amstrat grain size charts
- Knife
- Acid (10 percent Hcl) in squirt bottle
- Water in squirt bottle
- Markers (black, waterproof)
- Protective clothing and equipment (see Health & Safety Plan)
- Pens (black, waterproof)
- Flashlight
- Hammer
- Clipboard
- Table

- Duct tape
- Paper towels
- Plastic wrap

6.2 CORE BOXES

The core boxes should be similar to the boxes described in Subsection 6.1 above. Each core box and lid should be marked with the following information:

- Well name
- Location
- Surface elevation
- Depth
- Date
- Project number
- Logger's initials

After samples have been containerized, the remaining core will be placed in marked core boxes and transported to the core storage facility. In addition to markings, the core boxes will be labeled and stored according to the results of field monitoring (organic vapor detectors and radiological screening) conducted during drilling and coring activities. (See SOP 1.8, Handling of Drilling Fluids and Cuttings and SOP 1.16, Field Radiological Measurements.)

Core boxes suspected of containing low-level radioactive substances only will be labeled with a "White I" radioactive label. Core boxes suspected of containing volatile organic or mixed substances will be labeled with a Department of Transportation "Other Regulated Material Class E" (ORM-E) label. (See SOP 1.10, Receiving, Labeling and Handling of Waste Containers.) If the suspected contamination is mixed substances, the core box will also be marked with the words "SUS RAD" for suspected radioactive contamination.

The core boxes will be then transported to the appropriate storage facility.

6.3 CORES AND CUTTINGS

6.3.1 Scanning the Core

After an interval of core has been cut and the sampler has been opened, the core will be scanned for hazardous and radioactive contamination. The field use of monitors for the detection of volatile organics and radionuclides is discussed in SOPs 1.8, Handling of Drilling Fluids and Cuttings; 1.15, Use of Photoionizing Detectors and Flame Ionizing Detectors; and 1.16, Field Radiological Instruments.

6.3.2 Percent Recovery

If the core is safe, the core should be consolidated in the sampler and slid out onto the plastic wrap that has been placed in the core box. Immediately following this, the core should be measured to the nearest tenth of a foot, and this measurement, along with the interval that was cut, should be recorded on the logging form. Figure 3.1-8 is an example of a completed logging form. Wood blocks with footage values marked on them in black waterproof ink should be placed at each end of the core. If only cuttings were collected, a representative sample should be collected every 2 feet, and this sample should be placed in a labeled jar in the core box.

6.3.3 Logging

The core or cuttings should be logged according to all of the procedures previously covered in this SOP.

ROCKY FLATS PLANT BOREHOLE LOG

Borehole Number: 192-86

Location - North: 749718.7 East: 2086747.7

Date: 10/26/86

Geologist: JBP

Drilling Equip.: Continuous Core/Hollow Stem Auger

Surface Elevation: 5962

Area: East Trenches

Total Depth: 30'

Company:

Project No.: 668-12.11

Sample Type: S & H Sampler

EG&G LOGGING SUPERVISOR

APPROVAL _____

DATE _____

TOP/BOTTOM OF CORE IN BOX	TOP/BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL IN BOX	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	LITHOLOGIC LOG	SAMPLE DESCRIPTION
0'	0'					80% Gravel				
		5.7'					GW	1		
								2		
								3		
								5		
	5.5'							6		No Sample
	6.2'					75% Gravel		7		
	6.2'						GP	8		
		3.8'						9		
12'	10.3'									

NOTES: General: USCS is modified for this log as follows:

Materials amounts are estimated by % volume instead of % weight.

(1) Badly broken core, accurate footage measurements not possible.

(2) Core breaks cannot be matched, accurate footage measurements not possible.

Figure 3.1-8

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ROCKY FLATS PLANT BOREHOLE LOG

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Borehole Number: 192-86
 Location - North: 749718.7 East: 2086747.7
 Date: 10/26/86
 Geologist: JBP
 Drilling Equip.: Continuous Core/Hollow Stem Auger

Surface Elevation: 5962
 Area: East Tranches
 Total Depth: 30'
 Company: Acme Drilling Project No.: 662-12.11
 Sample Type: S&H Sampler

TOP BOTTOM OF CORE IN BOX	TOP BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	LITHOLOGIC LOG	SAMPLE DESCRIPTION
0'	6.2'									Sandy gravel as above.
Box 1 of 3	10.3'							11		No Sample
12'	12'					85% Sand 210% Silt		12		Top of bedrock
Box 2 of 3	16.8'	4.2'						13		Sand, light brown (5 YR 5/1) yellowish brown (10 YR 4/2) yellowish orange (10 YR 6/6) to medium-grained, trace to some silt, well sorted, sub-rounded to rounded, highly friable, trace black grains, some very thin clay lenses at 14.5 and 15 feet, bedding not apparent, manganese staining throughout, slightly to moderately weathered.
	16.8'					60% Sand 35% Clay 5% Silt		17		Clayey sandstone, light brown gray (5 YR 6/1) to brown gray (5 YR 4/1), fine- to medium-grained, moderately sorted, subrounded to rounded, abundant iron cementation, moderately to slightly friable, bedding not apparent, moist, slightly weathered.
	20.8'	3.8'						18		
								19		
24.4'	20.8'									

NOTES: General: USCS is modified for this log as follows:

Materials amounts are estimated by % volume instead of % weight.

(1) Badly broken core, accurate footage measurements not possible.

(2) Core breaks cannot be matched, accurate footage measurements not possible.

Figure 3.1-8

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ROCKY FLATS PLANT BOREHOLE LOG

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Borehole Number: 192-26
 Location - North: 749718.7 East: 2086747.7
 Date: 10/26/86
 Geologist: JBP
 Drilling Equip.: Continuous Core/Hollow Stem Augers

Surface Elevation: 5962
 Area: East Trenches
 Total Depth: 30'
 Company: Acme Drilling Project No.: 668-12.11
 Sample Type: S & H Sampler

TOP/BOTTOM OF CORE IN BOX	TOP/BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL IN BOX	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	LITHOLOGICAL LOG	SAMPLE DESCRIPTION
12'	16.8'									Clayey sandstone as above with iron nodule at 20.4'.
Box 2 of 3	20.8'					90% clay		21		Claystone, olive gray (5 Y 4/1) to olive black (5 Y 2/1), bedding not apparent, brittle due to healed fractures with abundant slickensides at 80-85°; unweathered.
	20.2'					10% S.H.		22		
								23		
								24		
	24.4'									
Box 3 of 3	24.4'					75% Sand				sandstone, medium light gray (N 6/0), very fine-grained, well sorted, subrounded, well cemented, slightly friable, trough cross-stratification with sets 1/2 to 1 foot thick between 27 and 30 feet, fractures from 45° to 85°, some filled with calcareous material, dry to moist, unweathered.
								26		
								27		
								28		
								29		
30'	30'									

NOTES: General: USCS is modified for this log as follows:

Materials amounts are estimated by % volume instead of % weight.

(1) Badly broken core, accurate footage measurements not possible.

(2) Core breaks cannot be matched, accurate footage measurements not possible.

Figure 3.1-8

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6.3.4 Photographing the Core

Any and all photographing procedures must conform to plant security controls. Each box of core should be photographed with a 35 mm camera after it has been logged and before the core is sampled. If the core is photographed at RFP, the camera will have to be cleared and left on site until the project is completed. In addition, all of the film must be processed by RFP. An identification tag and a Kodak color patch should appear in each photograph. The identification tag should contain:

- The well name
- Footage values of the core in the box
- The box number of the total number of boxes for that borehole, such as
Box 1 of 7
- Date core was taken
- Project number

6.3.5 Sampling

Samples that are taken for grain size analyses and permeameter tests should be removed only after the core has been logged and photographed. At the time a sample is taken, a wood block with the following information must be placed in the core box at the point the sample was removed:

- Sample number
- Depth
- Purpose
- Date
- Company

This information should be marked on the wood block with a black waterproof marker.

EG&G ROCKY FLATS PLANT
EMAD GEOTECHNICAL SOP

Safety Related
Category 1

Manual:
Procedure No.:
Page:
Effective Date:
Organization:

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ER&WM

7.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting all information required by the SOP on the Borehole Log Form. Drilling activities will also be documented on the hollow-stem auger or rotary and core drilling Field Activities Report Forms (see SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques, and SOP 3.4, Rotary Drilling and Rock Coring).

The logger will primarily be responsible for each aspect and each procedure.

PAGE OF

Surface Elevation:

East:

Area:

Total Depth:

Company:

Project No.:

Drilling Equip.:

Sample Type:

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APPROVAL

DATE _____

NOTES: General: USCS is modified for this log as follows:
Materials amounts are estimated by % volume instead of % weight.
(1) Badly broken core, accurate footage measurements not possible.
(2) Core breaks cannot be matched, accurate footage measurements not possible.

APPENDIX A
UNIFIED SOIL CLASSIFICATION SYSTEM
CHARACTERISTICS OF SOIL GROUPS
PERTAINING TO EMBANKMENTS AND FOUNDATIONS

THE UNIFIED SOIL CLASSIFICATION SYSTEM - APPENDIX A:
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS
AND FOUNDATIONS - APPENDIX B: CHARACTERISTICS OF SOIL
GROUPS PERTAINING TO ROADS AND AIRFIELDS

(U.S.) Army Engineer Waterways Experiment Station
Vicksburg, MS

Apr 60

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

NTIS®

TECHNICAL MEMORANDUM NO. 3-357

THE UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
EMBANKMENTS AND FOUNDATIONS

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
ROADS AND AIRFIELDS



April 1960

(Reprinted May 1967)

Sponsored by

Office, Chief of Engineers
U. S. Army

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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Preface

The purpose of this manual is to describe and explain the use of the "Unified Soil Classification System" in order that identification of soil types will be on a common basis throughout the agencies using this system.

The program of military airfield construction undertaken by the Department of the Army in 1941 revealed at an early stage that existing soil classifications were not entirely applicable to the work involved. In 1942 the Corps of Engineers tentatively adopted the "Airfield Classification" of soils which had been developed by Dr. Arthur Casagrande of the Harvard University Graduate School of Engineering. As a result of experience gained since that time, the original classification has been expanded and revised in cooperation with the Bureau of Reclamation so that it applies not only to airfields but also to embankments, foundations, and other engineering features.

Acknowledgment is made to Dr. Arthur Casagrande, Professor of Soil Mechanics and Foundation Engineering, Harvard University, for permission to incorporate in this manual considerable information from the paper "Classification and Identification of Soils" published in Transactions, American Society of Civil Engineers, volume 113, 1948. This manual was prepared under the direction of the Office, Chief of Engineers, by the Soils Division, Waterways Experiment Station.

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UNIFIED SOIL CLASSIFICATION SYSTEM

Introduction

Need for a classification system

1. The adoption of the principles of soil mechanics by the engineering profession has inspired numerous attempts to devise a simple classification system that will tell the engineer the properties of a given soil. As a consequence, many classifications have come into existence based on certain properties of soils such as texture, plasticity, strength, and other characteristics. A few classification systems have gained fairly wide acceptance, but it is seldom that any particular system has provided the complete information on a soil that the engineer needs. Nearly every engineer who practices soil mechanics will add judgment and personal experience as modifiers to whatever soil classification system he uses, so that it may be said that there are as many classification systems as there are engineers using them. Obviously, within a given agency, where designs and plans are reviewed by persons entirely removed from a project, a common basis of soil classification is necessary so that when an engineer classifies a soil as a certain type, this classification will convey to another engineer not familiar with the region the proper characteristics and behavior of the material. Further than this, the classification should reflect those behavior characteristics of the soil that are pertinent to the project under consideration.

Basis of the unified soil classification system

2. The unified soil classification system is based on the

identification of soils according to their textural and plasticity qualities and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component, but are usually found as mixtures with varying proportions of particles of different sizes; each component part contributes its characteristics to the soil mixture. The unified soil classification system is based on those characteristics of the soil that indicate how it will behave as an engineering construction material. The following properties have been found most useful for this purpose and form the basis of soil identification. They can be determined by simple tests and with experience can be estimated with some accuracy.

- a. Percentages of gravel, sand, and fines (fraction passing No. 200 sieve).
- b. Shape of the grain-size-distribution curve.
- c. Plasticity and compressibility characteristics.

In the unified soil classification system the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

Purpose and scope of manual

3. It is the purpose of this manual to describe the various soil groups in detail and to discuss the methods of identification in order that a uniform classification procedure may be followed by all who use the system. Placement of the soils into their respective groups is accomplished by visual examination and laboratory tests as a means of basic identification. This procedure is described in the main text of this manual. The classification of the soils in these groups according to their engineering behavior for various types of construction, such as

embankments, foundations, roads, and airfields, is treated separately in appendices hereto which will be issued as the need arises. It is recognized that the unified classification system in its present form may not prove entirely adequate in all cases. However, it is intended that the classification of soils in accordance with this system have some degree of elasticity, and that the system not be followed blindly nor regarded as completely rigid.

Definitions of soil components

4. Before soils can be classified properly in any system, including the one presented in this manual, it is necessary to establish a basic terminology for the various soil components and to define the terms used. In the unified soil classification the names "cobbles," "gravel," "sand," and "fines (silt or clay)" are used to designate the size ranges of soil particles. The gravel and sand ranges are further subdivided into the groups presented below. The limiting boundaries between the various size ranges have been arbitrarily set at certain U. S. Standard sieve sizes in accordance with the following tabulation:

<u>Component</u>	<u>Size Range</u>
Cobbles	Above 3 in.
Gravel	3 in. to No. 4 (4.76 mm)
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 (4.76 mm)
Sand	No. 4 (4.76 mm) to No. 200 (0.074 mm)
Coarse sand	No. 4 (4.76 mm) to No. 10 (2.0 mm)
Medium sand	No. 10 (2.0 mm) to No. 40 (0.42 mm)
Fine sand	No. 40 (0.42 mm) to No. 200 (0.074 mm)
Fines (silt or clay)	Below No. 200 (0.074 mm)

These ranges are shown graphically on the grain-size sheet, plate 1. In

the finest soil component (below No. 200 sieve) the terms "silt" and "clay" are used respectively to distinguish materials exhibiting lower plasticity from those with higher plasticity. The minus No. 200 sieve material is "silt" if the liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2), and is "clay" if the liquid limit and plasticity index plot above the "A" line on the chart (all Atterberg limits tests based on minus No. 40 sieve fraction of a soil). The foregoing definition holds for inorganic silts and clays and for organic silts, but is not valid for organic clays since these latter soils plot below the "A" line. The names of the basic soil components can be used as nouns or adjectives in the name of a soil, as explained later.

4 The Classification System

5. A short discussion of the unified soil classification sheet, table 1, is presented in order that the succeeding detailed description may be more easily understood. This sheet is designed to apply generally to the identification of soils regardless of the intended engineering uses. The first three columns of the classification sheet show the major divisions of the classification and the group symbols that distinguish the individual soil types. Names of typical and representative soil types found in each group are shown in column 4. The field procedures for identifying soils by general characteristics and from pertinent tests and visual observations are shown in column 5. The desired descriptive information for a complete identification of a soil is presented in column 6. In column 7 are presented the laboratory

classification criteria by which the various soil groups are identified and distinguished. Table 2 shows an auxiliary schematic method of classifying soils from the results of laboratory tests. The application and use of this chart are discussed in greater detail under a subsequent heading in this manual.

Soil groups and group symbols

6. Major divisions. Soils are primarily divided into coarse-grained soils, fine-grained soils, and highly organic soils. On a textural basis, coarse-grained soils are those that have 50 per cent or less of the constituent material passing the No. 200 sieve, and fine-grained soils are those that have more than 50 per cent passing the No. 200 sieve. Highly organic soils are in general readily identified by visual examination. The coarse-grained soils are subdivided into gravel and gravelly soils (symbol G), and sands and sandy soils (symbol S). Fine-grained soils are subdivided on the basis of the liquid limit; symbol L is used for soils with liquid limits of 50 and less, and symbol H for soils with liquid limits in excess of 50 (see plate 2). Peat and other highly organic soils are designated by the symbol Pt and are not subdivided.

7. Subdivisions, coarse-grained soils. In general practice there is no clear-cut boundary between gravelly soils and sandy soils, and as far as behavior is concerned the exact point of division is relatively unimportant. For purposes of identification, coarse-grained soils are classed as gravels (G) if the greater percentage of the coarse fraction (retained on No. 200 sieve) is larger than the No. 4 sieve and as sands (S) if the greater portion of the coarse fraction is finer than the No. 4

sieve. Borderline cases may be classified as belonging to both groups. The gravel (G) and sand (S) groups are each divided into four secondary groups as follows:

- a. Well-graded material with little or no fines. Symbol W. Groups GW and SW.
- b. Poorly-graded material with little or no fines. Symbol P. Groups GP and SP.
- c. Coarse material with nonplastic fines or fines with low plasticity. Symbol M. Groups GM and SM.
- d. Coarse material with plastic fines. Symbol C. Groups GC and SC.

8. Subdivisions, fine-grained soils. The fine-grained soils are subdivided into groups based on whether they have a relatively low (L) or high (H) liquid limit. These two groups are further subdivided as follows:

- a. Inorganic silts and very fine sandy soils; silty or clayey fine sands; micaceous and diatomaceous soils; elastic silts. Symbol M. Groups ML and MH.
- b. Inorganic clays. Symbol C. Groups CL and CH.
- c. Organic silts and clays. Symbol O. Groups OL and OH.

Discussion of Coarse-grained Soils

GW and SW groups

9. These groups comprise well-graded gravelly and sandy soils having little or no nonplastic fines (less than 5 per cent passing the No. 200 sieve). The presence of the fines must not noticeably change the strength characteristics of the coarse-grained fraction and must not interfere with its free-draining characteristics. If the material contains less than 5 per cent fines that exhibit plasticity, this

information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." In areas subject to frost action, the material should not contain more than about 3 per cent of soil grains smaller than 0.02 mm in size. Typical examples of GW and SW soils are shown on plate 3.

GP and SP groups

10. Poorly-graded gravels and sands containing little or no non-plastic fines (less than 5 per cent passing the No. 200 sieve) are classed in the GP and SP groups. The materials may be classed as uniform gravels, uniform sands, or nonuniform mixtures of very coarse material and very fine sand, with intermediate sizes lacking (sometimes called skip-graded, gap-graded, or step-graded). The latter group often results from borrow excavation in which gravel and sand layers are mixed. If the fine fraction exhibits plasticity, this information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." Typical examples of various types of GP and SP soils are shown on plate 4.

GM and SM groups

11. In general, the GM and SM groups comprise gravels or sands with fines (more than 12* per cent passing the No. 200 sieve) having low or no plasticity. The plasticity index and liquid limit (based on minus No. 40 sieve fraction) of soils in the group should plot below the "A" line on

* In the preceding two paragraphs soils of the GW, GP, SW, and SP groups were defined as having less than 5 per cent passing the No. 200 sieve. Soils which have between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33 under that heading.

the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included. Some of the sands and gravels in this group will have a binder composed of natural cementing agents, so proportioned that the mixture shows negligible swelling or shrinkage. Thus the dry strength of such materials is provided by a small amount of soil binder or by cementation of calcareous material or iron oxide. The fine fraction of other materials in the GM and SM groups may be composed of silts or rock flour types having little or no plasticity and the mixture will exhibit no dry strength. Typical examples of types of GM and SM soils are shown on plate 5.

GC and SC groups

12. In general, the GC and SC groups comprise gravelly or sandy soils with fines (more than 12 per cent passing the No. 200 sieve) which have either low or high plasticity. The plasticity index and liquid limit of soils (fraction passing the No. 40 sieve) in the group should plot above the "A" line on the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does variation in gradation. The fine fraction is generally composed of clays. Typical examples of GC and SC soils are shown on plate 6.

Discussion of Fine-grained Soils

ML and MH groups

13. In these groups the symbol M has been used to designate

predominantly silty materials and micaceous or diatomaceous soils. The symbols L and H represent low and high liquid limits, respectively, and an arbitrary dividing line between the two is set at a liquid limit of 50. The soils in the ML and MH groups are sandy silts, clayey silts, or inorganic silts with relatively low plasticity. Also included are loess-type soils and rock flours. Micaceous and diatomaceous soils generally fall within the MH group but may extend into the ML group when their liquid limit is less than 50. The same is true for certain types of kaolin clays and some illite clays having relatively low plasticity. Typical examples of soils in the ML and MH groups are shown on plate 7.

CL and CH groups

14. In these groups the symbol C stands for clay, with L and H denoting low or high liquid limit. The soils are primarily inorganic clays. Low plasticity clays are classified as CL and are usually lean clays, sandy clays, or silty clays. The medium and high plasticity clays are classified as CH. These include the fat clays, gumbo clays, certain volcanic clays, and bentonite. The glacial clays of the northern United States cover a wide band in the CL and CH groups. Typical examples of soils in these groups are shown on plate 8.

OL and OH groups

15. The soils in the OL and OH groups are characterized by the presence of organic matter, hence the symbol O. Organic silts and clays are classified in these groups. The materials have a plasticity range that corresponds with the ML and MH groups. Typical examples of OL and OH soils are presented on plate 9.

Discussion of Highly Organic Soils

Pt group

16. The highly organic soils usually are very compressible and have undesirable construction characteristics. They are not subdivided and are classified into one group with the symbol Pt. Peat, humus, and swamp soils with a highly organic texture are typical soils of the group. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

Identification of Soil Groups

17. The unified soil classification is so arranged that most soils may be classified into at least the three primary groups (coarse grained, fine grained, and highly organic) by means of visual examination and simple field tests. Classification into the subdivisions can also be made by visual examination with some degree of success. More positive identification may be made by means of laboratory tests on the materials. However, in many instances a tentative classification determined in the field is of great benefit and may be all the identification that is necessary, depending on the purposes for which the soils in question are to be used. Methods of general identification of soils are discussed in the following paragraphs, and a laboratory testing procedure is presented. It is emphasized that the two methods of identification are never entirely separated. Certain characteristics can only be estimated by visual examination, and in borderline cases it may be necessary to verify the classification by laboratory tests. Conversely, the field

methods are entirely practical for preliminary laboratory identification and may be used to advantage in grouping soils in such a manner that only a minimum number of laboratory tests need be run.

General Identification

18. The easiest way of learning field identification of soils is under the guidance of experienced personnel. Without such assistance, field identification may be learned by systematically comparing the numerical test results for typical soils in each group with the "feel" of the material while field identification procedures are being performed.

Coarse-grained soils

19. Texture and composition. In field identification of coarse-grained materials a dry sample is spread on a flat surface and examined to determine gradation, grain size and shape, and mineral composition. Considerable experience is required to differentiate, on the basis of a visual examination, between well-graded and poorly-graded soils.

The durability of the grains of a coarse-grained soil may require a careful examination, depending on the use to which the soil is to be put. Pebbles and sand grains consisting of sound rock are easily identified. Weathered material is recognized from its discolorations and the relative ease with which the grains can be crushed. Gravels consisting of weathered granitic rocks, quartzite, etc., are not necessarily objectionable for construction purposes. On the other hand, coarse-grained soils containing fragments of shaley rock may be unsuitable because alternate wetting and drying may result in their partial or complete disintegration. This property can be identified by a slaking test.

The particles are first thoroughly oven- or sun-dried, then submerged in water for at least 24 hours, and finally their strength is tested and compared with the original strength. Some types of shales will completely disintegrate when subjected to such a slaking test.

20. Examination of fine fraction. Reference to the identification sheet (table 1) shows that classification criteria of the various coarse-grained soil groups are based on the amount of material passing the No. 200 sieve and the plasticity characteristics of the binder fraction (passing the No. 40 sieve). Various methods may be used to estimate the percentage of material passing the No. 200 sieve; the choice of method will depend on the skill of the technician, the equipment at hand, and the time available. One method, decantation, consists of mixing the soil with water in a suitable container and pouring off the turbid mixture of water and fine soil; successive decantations will remove practically all of the fines and leave only the sand and gravel sizes in the container. A visual comparison of the residue with the original material will give some idea of the amount of fines present. Another useful method is to put a mixture of soil and water in a test tube, shake it thoroughly, and allow the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 seconds. If the assumption is made that the soil weight is proportional to its volume, this method may be used to estimate the amount of fines present. A rough estimate of the amount of fines may be made by spreading the sample out on a level surface and making a visual estimate of the percentage of fine particles present. The presence of fine sand can

usually be detected by rubbing a sample between the fingers; silt or clay particles feel smooth and stain the fingers, whereas the sand feels gritty and does not leave a stain. The "teeth test" is sometimes used for this purpose, and consists of biting a portion of the sample between the teeth. Sand feels gritty whereas silt and clay do not; clay tends to stick to the teeth while silt does not. If there appears to be more than about 12 per cent of the material passing the No. 200 sieve, the sample should be separated as well as possible by hand, or by decantation and evaporation, removing all of the gravel and coarse sand, and the characteristics of the fine fraction determined. The binder is mixed with water and its dry strength and plasticity characteristics are examined. Criteria for dry strength are shown in column 5 of the classification sheet, table 1; evaluation of soils according to dry strength and plasticity criteria is discussed in succeeding paragraphs in connection with fine-grained soils. Identification of active cementing agents other than clay usually is not possible by visual and manual examination, since such agents may require a curing period of days or even weeks. In the absence of such experience the soils should be classified tentatively into their apparent groups, neglecting any possible development of strength because of cementation.

Fine-grained soils

21. The principal procedures for field identification of fine-grained soils are the test for dilatancy (reaction to shaking), the examination of plasticity characteristics, and the determination of dry strength. In addition, observations of color and odor are of value, particularly for organic soils. Descriptions of the field identification

procedures are presented in the following paragraphs. The dilatancy, plasticity, and dry strength tests are performed on the fraction of the soil finer than the No. 40 sieve. Separation of particles coarser than the No. 40 sieve is done most expediently in the field by hand. However, separation by hand probably will be most effective for particles coarser than the No. 10 sieve. Some effort should be made to remove the No. 10 to No. 40 fraction but it is believed that any particles in this size range remaining after hand separation would have little effect on the field identification procedures.

22. Dilatancy. The soil is prepared for test by removing particles larger than about the No. 40 sieve size (by hand) and adding enough water, if necessary, to make the soil soft but not sticky. The pat of moist soil should have a volume of about 1/2 cubic inch. The pat of soil is alternately shaken horizontally in the open palm of one hand, which is struck vigorously against the other hand several times, and then squeezed between the fingers. A fine-grained soil that is nonplastic or exhibits very low plasticity will become livery and show free water on the surface while being shaken. Squeezing will cause the water to disappear from the surface and the sample to stiffen and finally crumble under increasing finger pressure, like a brittle material. If the water content is just right, shaking the broken pieces will cause them to liquefy again and flow together. A distinction may be made between rapid, slow, or no reaction to the shaking test, depending on the speed with which the pat changes its consistency and the water on the surface appears or disappears. Rapid reaction to the shaking test is typical for nonplastic, uniform fine sand, silty sand (SP, SM), and inorganic silts (ML)

particularly of the rock-flour type, also for diatomaceous earth (MH). The reaction becomes somewhat more sluggish with decreasing uniformity of gradation (and increase in plasticity up to a certain degree). Even a slight content of colloidal clay will impart to the soil some plasticity and slow up materially the reaction to the shaking test. Soils which react in this manner are somewhat plastic inorganic and organic silts (ML, OL), very lean clays (CL), and some kaolin-type clays (ML, MH). Extremely slow or no reaction to the shaking test is characteristic of all typical clays (CL, CH) as well as of highly plastic organic clays (OH).

23. Plasticity characteristics. Examination of the plasticity characteristics of fine-grained soils or of the fine fraction of coarse-grained soils is made with a small moist sample of the material. Particles larger than about the No. 40 sieve size are removed (by hand) and a specimen of soil about the size of a 1/2-in. cube is molded to the consistency of putty. If the soil is too dry, water must be added and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. The sample is rolled by hand on a smooth surface or between the palms into a thread about 1/8 in. in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. The higher the position of a soil above the "A" line on the plasticity chart, plate 2 (CL, CH), the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the

soil is remolded after rolling. Soils slightly above the "A" line (CL, CH) form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily. Soils below the "A" line (ML, MH, OL, OH) form a weak thread and, with the exception of the OH soils, cannot be lumped together into a coherent mass below the plastic limit. Plastic soils containing organic material or much mica (well below the "A" line) form threads that are very soft and spongy near the plastic limit. The binder fraction of coarse-grained soils may be examined in the same manner as fine-grained soils. In general, the binder fraction of coarse-grained soils with silty fines (GM, SM) will exhibit plasticity characteristics similar to the ML soils, and that of coarse-grained soils with clayey fines (GC, SC) will be similar to the CL soils.

24. Dry strength. The resistance of a piece of dried soil to crushing by finger pressure is an indication of the character of the colloidal fraction of a soil. To initiate the test, particles larger than the No. 40 sieve size are removed from the soil (by hand) and a specimen is molded to the consistency of putty, adding water if necessary. The moist pat of soil is allowed to dry (in oven, sun, or air) and is then crumbled between the fingers. Soils with slight dry strength crumble readily with very little finger pressure. All nonplastic ML and MH soils have almost no dry strength. Organic silts and lean organic clays of low plasticity (OL), as well as very fine sandy soils (SM), have slight dry strength. Soils of medium dry strength require considerable finger pressure to powder the sample. Most clays of the CL group and some OH soils exhibit medium dry strength. This is also true of the fine

fraction of gravelly and sandy soils having a clay binder (GC and SC). Soils with high dry strength can be broken but cannot be powdered by finger pressure. High dry strength is indicative of most CH clays, as well as some organic clays of the OH group having very high liquid limits and located near the A-line. In some instances high dry strength in the undisturbed state may be furnished by a cementing material such as calcium carbonate or iron oxide.

25. Color. In field soil surveys color is often helpful in distinguishing between various soil strata, and to an engineer with sufficient preliminary experience with the local soils, color may also be useful for identifying individual soils. The color of the moist soil should be used in identification as soil color may change markedly on drying. To the experienced eye certain dark or drab shades of gray or brown, including almost black colors, are indicative of fine-grained soils containing organic colloidal matter (OL, OH). In contrast, brighter colors, including medium and light gray, olive green, brown, red, yellow, and white, are generally associated with inorganic soils. Use of the Munsell soil color charts and plates, prepared for the U. S. Department of Agriculture by the Munsell Color Company, Baltimore, Maryland, is suggested in the event more precise soil color descriptions are desired or to facilitate uniform naming of soil colors.

26. Odor. Organic soils of the OL and OH groups usually have a distinctive odor which, with experience, can be used as an aid in the identification of such materials. This odor is especially apparent from fresh samples. It gradually diminishes on exposure to air, but can be revived by heating a wet sample.

Highly organic soils

27. The field identification of highly organic soils (group Pt) is relatively easy inasmuch as these soils are characterized by undecayed or partially carbonized particles of leaves, sticks, grass, and other vegetable matter which impart to the soil a typical fibrous texture. The color ranges generally from various shades of dull brown to black. A distinct organic odor is also characteristic of the soil. The water content is usually very high. Another aid in identification of these soils may be the location of the soil with respect to topography: low-lying, swampy areas usually contain highly organic soils.

Laboratory Identification

28. The identification of soils in the laboratory is accomplished by determining the gradation and plasticity characteristics of the materials. The gradation is determined by sieve analysis and a grain-size curve is usually plotted as per cent finer (or passing) by weight against a logarithmic scale of grain size in millimeters. Plate 1 is a typical grain-size chart. Plasticity characteristics are evaluated by means of the liquid and plastic limits tests on the soil fraction finer than the No. 40 sieve. A suggested laboratory method of identification is presented schematically in the chart shown as table 2 and is discussed in the succeeding paragraphs. It should be recognized that although a definite procedure for identification is outlined on the chart, the laboratory technician engaged in classification may be able to use "short cuts" in his work after he becomes thoroughly familiar with the criteria for each soil group.

Identification of major soil groups

29. Reference to the identification procedure chart, table 2, shows that the first step in the laboratory identification of a soil is to determine whether it is coarse grained, fine grained, or highly organic. This may be done by visual examination in most cases, using the procedures outlined for field identification. In some borderline cases, as with very fine sands or coarse silts, it may be necessary to screen a representative dry sample over a No. 200 sieve and determine the percentage passing. Fifty per cent or less passing the No. 200 sieve identifies the soil as coarse grained, and more than 50 per cent identifies the soil as fine grained. The percentage limit of 50 has been selected arbitrarily for convenience in identification as it is obvious that a numerical difference of 1 or 2 in this percentage will make no significant change in the behavior of the soil. After the major group in which the soil belongs is established, the identification procedure is continued in accordance with the proper headings in the chart.

Identification of subgroups, coarse-grained soils

30. Gravels (G) or sands (S). A complete sieve analysis is run on coarse-grained soils and the gradation curve is plotted on a grain-size chart. For some soils containing a substantial amount of fines, it may be desirable to supplement the sieve analysis with a hydrometer analysis in order to define the gradation curve below the No. 200 sieve size. Preliminary identification is made by determining the percentage of material in the gravel (above No. 4 sieve) and sand (No. 4 to No. 200 sieve) sizes. If there is a greater percentage of gravel than sand the material is

classed as gravel (G); if there is a greater percentage of sand than gravel the material is classed as sand (S). Once again the distinction between these groups is purely arbitrary for convenience in following the system. The next identification step is to determine the amount of material passing the No. 200 sieve. Since the subgroups are the same for gravels and sands, they will be discussed jointly in the following paragraphs.

31. GW, SW, GP, and SP groups. These groups comprise nonplastic soils having less than 5 per cent passing the No. 200 sieve and in which the fine fraction does not interfere with the soils' free-draining properties. If the above criteria are met, an examination is made of the shape of the grain-size curve. Materials that are well graded are classified as GW or SW; poorly-graded materials are classified as GP or SP. The grain-size distributions of well-graded materials generally plot as smooth and regular concave curves with no sizes lacking or no excess of material in any size range (plate 3); the uniformity coefficient (60 per cent grain diameter divided by the 10 per cent grain diameter) of well-graded gravels is greater than 4, and of well-graded sands is greater than 6. In addition, the gradation curves should meet the following qualification in order to be classed as well graded.

$$\frac{(D_{30})^2}{D_{60} \times D_{10}} \text{ between 1 and 3}$$

where D_{30} = grain diameter at 30 per cent passing

D_{60} = grain diameter at 60 per cent passing

D_{10} = grain diameter at 10 per cent passing

The foregoing expression, termed a coefficient of curvature, insures

that the grading curve will have a concave curvature within relatively narrow limits for a given D_{60} and D_{10} combination. All gradations not meeting the foregoing criteria are classed as poorly graded. Thus, poorly-graded soils (GP, SP) are those having nearly straight line gradations (plate 4, fig. 1, curve 3), convex gradations, nearly vertical (uniform) gradations (plate 4, fig. 1, curve 1), and gradation curves with "humps" typical of skip-graded materials (plate 4, fig. 1, curve 2).

32. GM, SM, GC and SC groups. The soils in these groups are composed of those materials having more than a 12* per cent fraction passing the No. 200 sieve; they may or may not exhibit plasticity. For identification, the liquid and plastic limits tests are required on the fraction finer than the No. 40 sieve. The tests should be run on representative samples of moist material, and not on air- or oven-dried soils. This precaution is desirable as drying affects the limits values to some extent as will be explained further in the discussion of fine-grained soils. Materials in which the liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2) are classed as GM or SM (plate 5). Gravels and sands in which the liquid limit and plasticity index plot above the "A" line on the plasticity chart are classed as GC or SC (plate 6). It is considered that in the identification of materials in these groups the plasticity characteristics overshadow the gradation characteristics; therefore, no distinction is made between well- and poorly-graded materials.

* In the preceding paragraph soils of the GW, GP, SW, and SP groups were defined as having less than a 5 per cent fraction passing the No. 200 sieve. Soils having between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33.

33. Borderline soils. Coarse-grained soils containing between 5 and 12% material passing the No. 200 sieve are classed as borderline and carry a dual symbol, e.g., GW-GM. Similarly, coarse-grained soils having less than 5% passing the No. 200 sieve, but which are not free draining, or wherein the fine fraction exhibits plasticity, are also classed as borderline and are given a dual symbol. Additional discussion of borderline classification is presented in paragraphs 38-41.

Identification of sub-
groups, fine-grained soils

34. Use of plasticity chart. Once the identity of a fine-grained soil has been established, further identification is accomplished principally by the liquid and plastic limits tests in conjunction with the plasticity chart (plate 2). The plasticity chart was developed by Dr. Casagrande as the result of considerable experience with the behavior of soils in many different regions. It is a plot of liquid limit versus plasticity index on which is imposed a diagonal line called the "A" line and a vertical line at a liquid limit of 50. The "A" line is defined by the equation $PI = 0.73 (LL - 20)$. The "A" line above a liquid limit of about 29 represents an important empirical boundary between typical inorganic clays (CL and CH), which are generally located above the line, and plastic soils containing organic colloids (OL and OH) or inorganic silty soils (ML and MH). The vertical line at liquid limit of 50 separates silts and clays of low liquid limit (L) from those of high liquid limit (H). In the low part of the chart below a liquid limit of about 29 and in the range of PI from 4 to 7 there is considerable overlapping of the properties of the clayey and silty soil types. Hence, the separation between

CL and OL or ML soil types in this region is accomplished by a cross-hatched zone on the plasticity chart between 4 and 7 PI and above the "A" line. CL soils in this region are those having a PI above 7 while OL or ML soils are those having a PI below 4. Soils plotting within the cross-hatched zone should be classed as borderline as discussed later. The various soil groups are shown in their respective positions on the plasticity chart. Experience has shown that compressibility is approximately proportional to liquid limit and that soils having the same liquid limit possess approximately equal compressibility, assuming that other factors are essentially the same. On comparing the physical characteristics of soils having the same liquid limit, one finds that with increasing plasticity index, the cohesive characteristics increase and the permeability decreases. From plots of the results of limits tests on a number of samples from the same fine-grained deposit, it is found that for most soils these points lie on a straight line or in a narrow band approximately parallel to the "A" line. With this background information in mind, the identification of the various groups of fine-grained soils is discussed in the following paragraphs.

35. ML, CL, and OL groups. A soil having a liquid limit of less than 50 falls into the low liquid limit (L) group. A plot of the liquid limit and plasticity index on the plasticity chart will show whether it falls above or below the "A" line and cross-hatched zone. Soils plotting above the "A" line and cross-hatched zone are classed as CL and are usually typical inorganic clays (plate 8, fig. 1). Soils plotting below the "A" line or cross-hatched zone are inorganic silts or very fine sandy silts, ML (plate 7, fig. 1), or organic silts or organic silt-clays of low

plasticity, OL (plate 9, fig. 1). Since two groups fall below the "A" line or cross-hatched zone, further identification is necessary. The distinguishing factor between the ML and OL groups is the absence or presence of organic matter. This is usually identified by color and odor as explained in the preceding paragraphs under field identification. However, in doubtful cases a comparison may be made between the liquid and plastic limits of a moist sample and one that has been oven-dried. An organic soil will show a radical drop in plasticity after oven-drying or air-drying. An inorganic soil will generally show a change in the limits values of only 1 or 2% which may be either an increase or a decrease. For the foregoing reasons the classification should be based on the plot of limits values determined before drying. Soils containing organic matter generally have lower specific gravities and may have decidedly higher water contents than inorganic soils; therefore, these properties may be of assistance in identifying organic soils. In special cases, the determination of organic content may be made by chemical methods, but the procedures just described are usually sufficient.

36. MH, CH, and OH groups. Soils with a liquid limit greater than 50 are classed in group H. To identify such soils, the liquid limit and plasticity index values are plotted on the plasticity chart. If the points fall above the "A" line, the soil classifies as CH; if it falls below the "A" line, a determination is made as to whether or not organic material is present, as described in the preceding paragraph. Inorganic materials are classed as MH and organic materials are classed as OH.

Identification of highly organic soils

37. Little more can be said as to the laboratory identification of

highly organic soils (Pt) than has been stated previously under field identification. These soils are usually identified readily on the basis of color, texture, and odor. Moisture determinations usually show a natural water content of several hundred per cent, which is far in excess of that found for most soils. Specific gravities of the solids in these soils may be quite low. Some peaty soils can be remolded and tested for liquid and plastic limits. Such materials usually have a liquid limit of several hundred per cent and fall well below the "A" line on the plasticity chart.

Borderline classifications

38. It is inevitable in the use of the classification system that soils will be encountered that fall close to the boundaries established between the various groups. In addition, boundary zones for the amount of material passing the No. 200 sieve and for the lower part of the plasticity chart have been incorporated as a part of the system, as discussed subsequently. The accepted rule in classifying borderline soils is to use a double symbol; for example, GW-GM. It is possible, in rare instances, for a soil to fall into more than one borderline zone and, if appropriate symbols were used for each possible classification, the result would be a multiple designation consisting of three or more symbols. This approach is unnecessarily complicated and it is considered best to use only a double symbol in these cases, selecting the two that are believed most representative of the probable behavior of the soil. In cases of doubt the symbols representing the poorer of the possible groupings should be used.

39. Coarse-grained soils. It will be recalled that in previous

discussions (paragraph 31) the coarse-grained soils were classified in the GW, GP, SW, and SP groups if they contained less than 5% of material passing the No. 200 sieve. Similarly, soils were classified in the GM, GC, SM, and SC groups if they had more than 12% passing the No. 200 sieve (paragraph 32). The range between 5 and 12% passing the No. 200 sieve is designated as borderline, and soils falling within it are assigned a double symbol depending on both the gradation characteristics of the coarse fraction and the plasticity characteristics of the minus No. 40 sieve fraction. For example, a well-graded sandy soil with 8% passing the No. 200 sieve and with $LL = 28$ and $PI = 9$ would be designated as SW-SC. Another type of borderline classification occurs for those soils containing appreciable amounts of fines, groups GM, GC, SM, and SC, and whose Atterberg limits values plot in the lower portion of the plasticity chart. The method of classifying these soils is the same as for fine-grained soils plotting in the same region, as presented in the following paragraph.

40. Fine-grained soils. Mention has been made of a zone on the plasticity chart (plate 2) below a liquid limit of about 29 and ranging between plasticity index values of 4 and 7. Several soil types exhibiting low plasticity plot in this general region on the plasticity chart and no definite boundary between silty and clayey soils exists. Thus, if a fine-grained soil, groups CL and ML, or the minus No. 40 sieve fraction of a coarse-grained soil, groups GM, GC, SM, and SC, plots within the cross-hatched zone on the plasticity chart, a double symbol (ML-CL, etc.) is used.

41. "Silty" and "clayey." It will be noted on the classification sheet, table 1, that the adjectives "silty" and "clayey" may be used as part of the descriptive name for silt or clay soils. Since the

definitions of these terms are now somewhat different from those used by many soils engineers, it is considered advisable to discuss their connotation as used in this system. In the unified soil classification the terms "silt" and "clay" are used to describe those soils with Atterberg limits plotting respectively below and above the "A" line and cross-hatched zone on the plasticity chart. As a logical extension of this concept, the terms "silty" and "clayey" may be used as adjectives in the soil names when the limits values plot close to the "A" line. For example, a clay soil with $LL = 40$ and $PI = 16$ may be called a silty clay. In general, the adjective "silty" is not applied to clay soils having a liquid limit in excess of about 60.

Expansion of Classification

42. It may be necessary, in some cases, to expand the unified classification system by subdivision of existing groups in order to classify soils for a particular use. The indiscriminate use of subdivisions is discouraged and careful study should be given any soil group before such a step is adopted. In all cases subdivisions should be designated preferably by a suffix to an existing group symbol. The suffix should be selected carefully so that there will be no confusion with existing letters that already have meanings in the classification system. In each case where an existing group is subdivided, the basis and criteria for the subdivision should be explained in order that anyone unfamiliar with it may understand the subdivision properly.

Descriptive Soil Classification

43. At many stages in the soils investigation of a project -- from the preliminary boring log to the final report -- the engineer finds it convenient to give the soils he is working with a "name" rather than an "impersonal" classification symbol such as GC. This results primarily from the fact that he is accustomed to talking in terms of gravels, sands, silts, and clays, and finds it only logical to use these same names in presenting the data. The soil names have been associated with certain grain sizes in the textural classification as shown on the grain-size chart, plate 1. Such a division is generally feasible for the coarse-grained soils; however, the use of such terms as silt and clay may be entirely misleading on a textural basis. For this reason the terms "silt" and "clay" have been defined on a plasticity basis as discussed previously. Within a given region of the country, use of a name classification based on texture is often feasible since the general behavior of similar soils is consistent over the area. However, in another area the same classification may be entirely inadequate. The descriptive classification, if used intelligently, has a rightful place in soil mechanics, but its use should be carefully evaluated by all concerned.

Description from classification sheet

44. Column 4 of the classification sheet, table 1, lists typical names given the soil types usually found within the various classification groups. By following either the field or laboratory investigation procedure and determining the proper classification group in which the soil

belongs, it is usually an easy matter to select an appropriate name from the classification sheet. Some soils may be readily identified and properly named by only visual inspection. A word of caution is considered appropriate on the use of the classification system for certain soils such as marls, caliches, coral, shale, etc., where the grain size can vary widely depending on the amount of mechanical breakdown of soil particles. For these soils the group symbol and textural name have little significance and the locally used name may be important.

Other descriptive terms

45. Records of field explorations in the form of boring logs can be of great benefit to the engineer if they include adequate information. In addition to the group symbol and the name of the soil, the general characteristics of the soils as to plasticity, strength, moisture, etc., provide information essential to a proper analysis of a particular problem. Locally accepted soil names should also be used to clarify the data to local bidders, and to protect the Government against later legal claims. For coarse-grained soils, the size of particles, mineralogical composition, shape of grains, and character of the binder are relevant features. For fine-grained soils, strength, moisture, and plasticity characteristics are important. When describing undisturbed soils such characteristics as stratification, structure, consistency in the undisturbed and remolded states, cementation, drainage, etc., are pertinent to the descriptive classification. Pertinent items to be used in describing soils are shown in column 6 of table 1. In order to achieve uniformity in estimating consistency of soils, it is recommended that the Terzaghi classification based on unconfined compressive strength be

used as a tentative standard. This classification is given below:

<u>Unconfined Compressive Strength</u> <u>Tons/Sq Ft</u>	<u>Consistency</u>
< 0.25	Very soft
0.25-0.50	Soft
0.50-1.00	Medium
1.00-2.00	Stiff
2.00-4.00	Very stiff
> 4.00	Hard

Several examples of descriptive classifications are shown below:

- a. Uniform, fine, clean sand with rounded grains (SP).
- b. Well-graded gravelly silty sand; angular chert gravel, 1/2-in. maximum size; silty binder with low plasticity, well-compacted and moist (SM).
- c. Light brown, fine, sandy silt; very low plasticity; saturated and soft in the undisturbed state (ML).
- d. Dark gray, fat clay; stiff in the undisturbed state; soft and sticky when remolded (CH).

(1m)					
Major Divisions		Cross-Symbols	Typical Names	Field Identification (Excluding particles in and having fraction on	
1	2	3	4	5	
Coarse-grained Soils More than half of material is larger than No. 200 sieve size. Sands More than half of coarse fraction is smaller than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size.) Gravels More than half of coarse fraction is larger than No. 4 sieve size.	Clean Gravels (little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes or amounts of all intermediate	
		GP	Poorly graded gravel or gravel-sand mixtures, little or no fines.	Predominantly one size or a some intermediate sizes m	
	Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines v. (for identification proc	
		GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identifi see CL below).	
	Clean Sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size or of all intermediate parti	
		SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a with some intermediate si	
	Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines v (for identification proc	
		SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identifi see CL below).	
				Identification on Fraction Smaller than	
				Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)
Fine-grained Soils More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye. Silt and Clays Liquid limit is less than 50 Silt and Clays Liquid limit is greater than 50	Silt and Clays Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sand or clayey silts with slight plasticity.	None to slight	Quick to s
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to ve slow
		OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow
	Silt and Clays Liquid limit is greater than 50	MH	Inorganic silts, micaceous or distamaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to no
		CH	Inorganic clays of high plasticity, fat clays.	High to very high	None
		OH	Organic clays of medium to high plasticity, crumbly silts.	Medium to high	None to ve slow
Highly Organic Soils		Pe	Peat and other highly organic soils.	Readily identified by color and frequently by fibrous	
(1) <u>Boundary classifications:</u> Soils possessing characteristic of two groups are designated by combinations of group					
FIELD IDENTIFICATION These procedures are to be performed on the minus No. 200 screening if not intended, simply					
Dilatancy (reaction to shaking)			Dry Strength (crushing char		
After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil. Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.			After removing particles consistency of pat, s by oven, sun, or air-d between the fingers. The colloidal fraction increasing plasticity. High dry strength is char ganic silt possesses or have about the same all when powdering the drit has the smooth feel of		

Table 1

UNITED SOIL CLASSIFICATION (Including Identification and Description)																							
Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)	Information Required for Describing Soils	Laboratory Classification Criteria																					
<p>So range in grain sizes and substantial amounts of all intermediate particle sizes.</p> <p>dominantly one size or a range of sizes with some intermediate sizes missing.</p> <p>plastic fines or fines with low plasticity (for identification procedures see ML below).</p> <p>little fines (for identification procedures see CL below).</p> <p>So range in grain size and substantial amounts of all intermediate particle sizes.</p> <p>dominantly one size or a range of sizes with some intermediate sizes missing.</p> <p>plastic fines or fines with low plasticity (for identification procedures see ML below).</p> <p>little fines (for identification procedures see CL below).</p>	<p>For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.</p> <p>Give typical name: indicate approximate percentages of sand and gravel, maximum size, angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.</p> <p>Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 1% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).</p>	<p> $C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 Not meeting all gradation requirements for GW </p> <p> Atterberg limits below "A" line or PI less than 4 Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols. </p> <p> $C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 Not meeting all gradation requirements for SK </p> <p> Atterberg limits below "A" line or PI less than 4 Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols. </p> <p>Atterberg limits above "A" line with PI greater than 7</p>																					
<p>Identification Procedures for Fraction Smaller than No. 40 Sieve Size</p> <table border="1"> <thead> <tr> <th>Strength (Crushing Characteristics)</th><th>Dilatancy (Reaction to shearing)</th><th>Toughness (Consistency near PL)</th></tr> </thead> <tbody> <tr> <td>Very slight</td><td>Quick to slow</td><td>None</td></tr> <tr> <td>None to high</td><td>None to very slow</td><td>Medium</td></tr> <tr> <td>High to medium</td><td>Slow</td><td>Slight</td></tr> <tr> <td>Low to slight</td><td>Slow to none</td><td>Slight to medium</td></tr> <tr> <td>None to very slight</td><td>None</td><td>High</td></tr> <tr> <td>None to high</td><td>None to very slow</td><td>Slight to medium</td></tr> </tbody> </table> <p>Soil identified by color, odor, spongy feel or frequently by fibrous texture.</p>	Strength (Crushing Characteristics)	Dilatancy (Reaction to shearing)	Toughness (Consistency near PL)	Very slight	Quick to slow	None	None to high	None to very slow	Medium	High to medium	Slow	Slight	Low to slight	Slow to none	Slight to medium	None to very slight	None	High	None to high	None to very slow	Slight to medium	<p>For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.</p> <p>Give typical name: indicate degree and character of plasticity; maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.</p> <p>Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).</p>	<p>Use grain-size curve in identifying the fractions as given under field identification.</p> <p>Determine percentages of gravel and sand from grain-size curve. Determine percentages of fines (fraction smaller than No. 200 sieve size) corresponding to the curve. Use of dual symbols.</p> <p>Less than 5% = ML, CL, OL, SP, SC, SW, etc. More than 5% = MH, MC, MH, etc. 5% to 15% = Borderline cases requiring use of dual symbols.</p> <p>Plasticity Chart</p> <p>For laboratory classification of fine-grained soils:</p>
Strength (Crushing Characteristics)	Dilatancy (Reaction to shearing)	Toughness (Consistency near PL)																					
Very slight	Quick to slow	None																					
None to high	None to very slow	Medium																					
High to medium	Slow	Slight																					
Low to slight	Slow to none	Slight to medium																					
None to very slight	None	High																					
None to high	None to very slow	Slight to medium																					

Examinations of group symbols. For example CH-OC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS
Formed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, not intended, simply remove by hand the coarse particles that interfere with the tests.

Strength (crushing characteristics)

For removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely (oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

So dry strength is characteristic for clays of the CH group. A typical loess-silt possesses only very slight dry strength. Silty fine sands and silts are about the same slight dry strength, but can be distinguished by the feel and spongy feel of the specimens. Fine sand feels gritty whereas a typical silt as the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

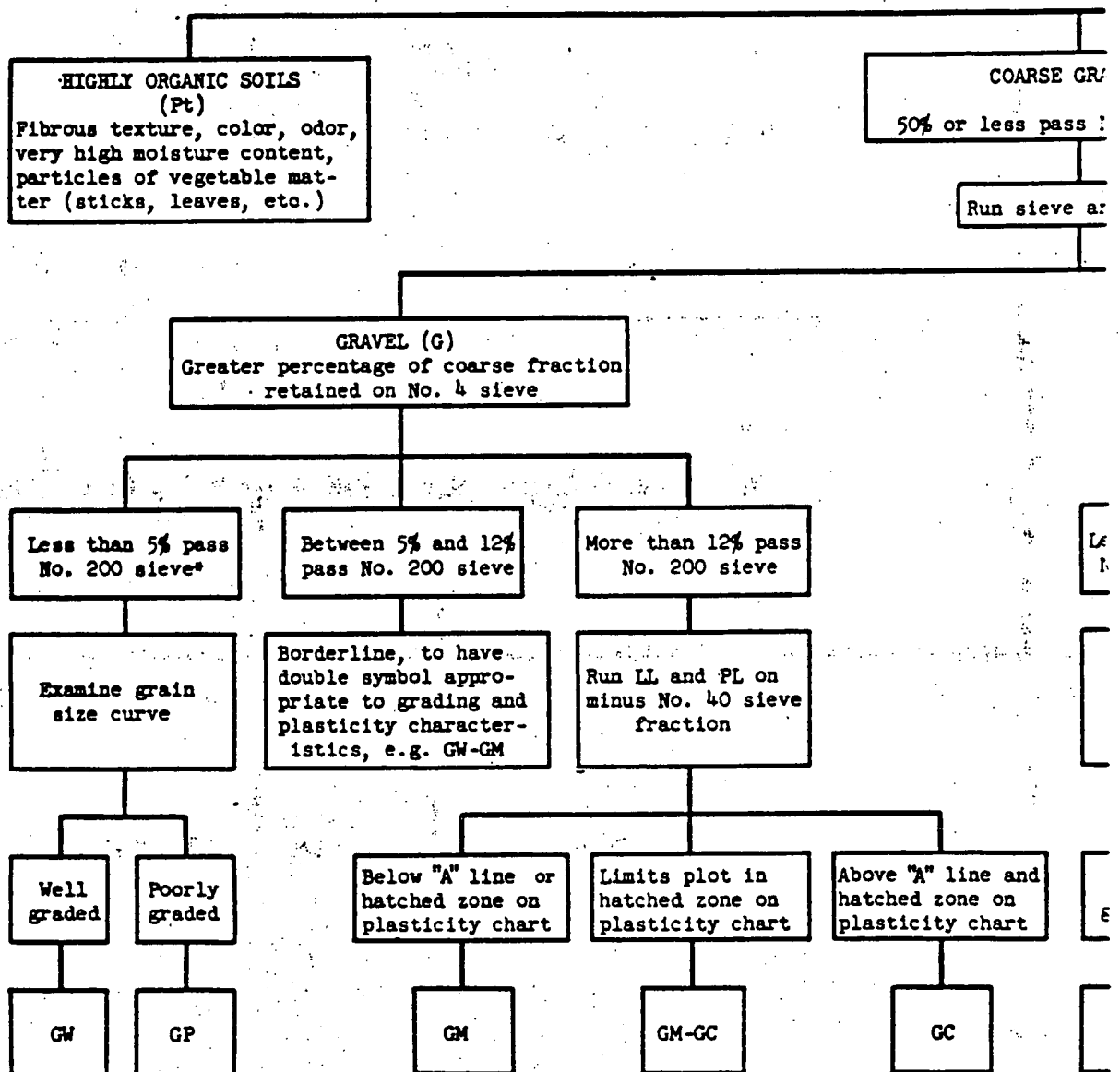
The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of cohesiveness of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line. Highly organic clays have a very spongy and spongy feel at the plastic limit.

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318

31.0



Note: Sieve sizes are U. S. Standard.

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* If fines interfere with free draining properties use double symbol such as GW-GM, etc.

021260-B

32-A

Table 2

AUXILIARY LABORATORY IDENTIFICATION PROCEDURE

Make visual examination of soil to determine whether it is HIGHLY ORGANIC, COARSE GRAINED, OR FINE GRAINED. In borderline cases determine amount passing No. 200 sieve.

COARSE GRAINED
pass No. 200 sieve

sieve analysis

SAND (S)
Greater percentage of coarse fraction
pass No. 4 sieve

Less than 5% pass
No. 200 sieve*

Examine grain
size curve

Well
graded

Poorly
graded

SW

SP

Between 5% and 12%
pass No. 200 sieve

Borderline, to have
double symbol appro-
priate to grading and
plasticity character-
istics, e.g. SW-SM

Below "A" line or
hatched zone on
plasticity chart

SM

More than 12% pass
No. 200 sieve

Run LL and PL on
minus No. 40 sieve
fraction

Below "A" line or
hatched zone on
plasticity chart

Limits plot in
hatched zone on
plasticity chart

Above "A" line and
hatched zone on
plasticity chart

SM-SC

SC

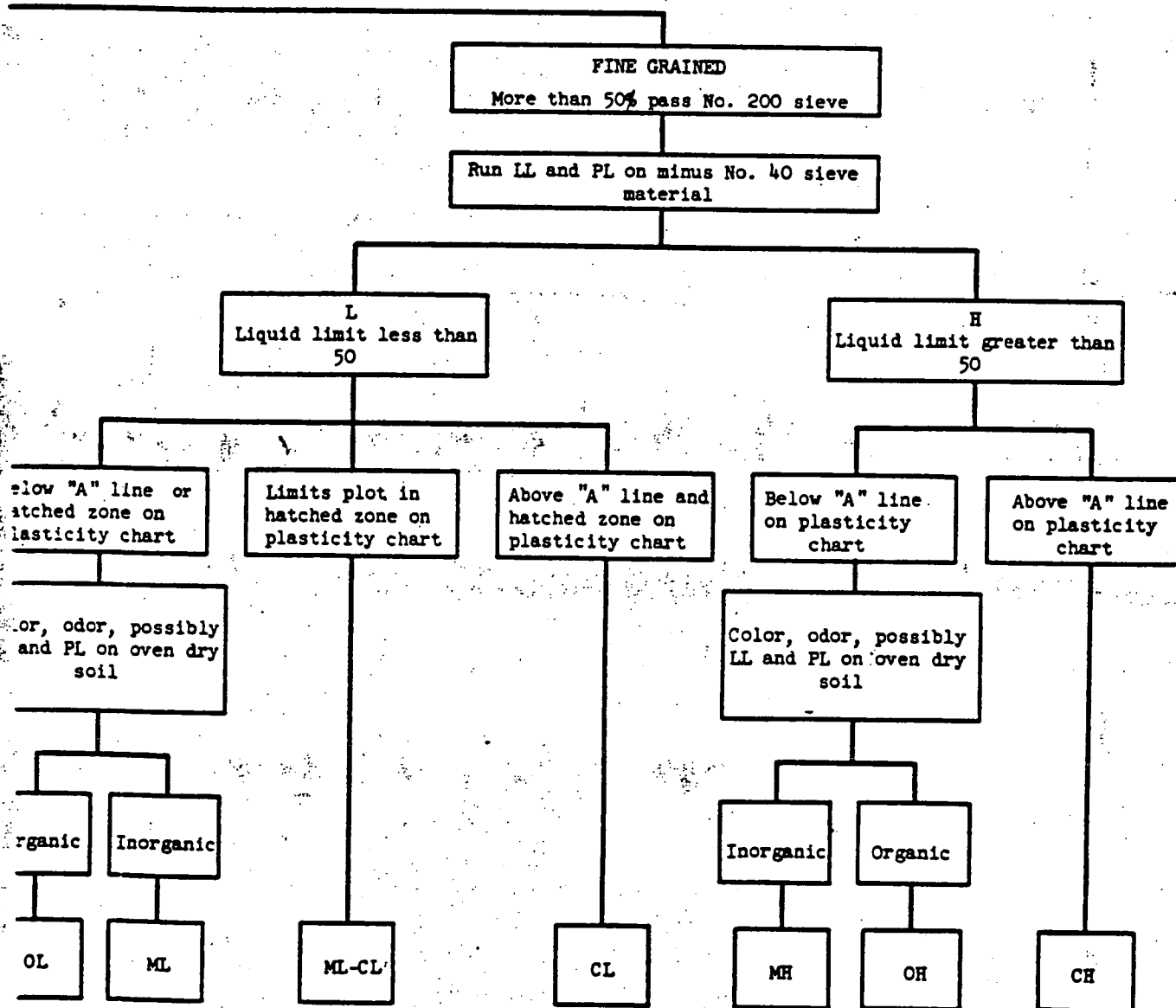
Below "A" line
hatched zone
plasticity

Color, odor,
LL and PL on
soil

Organic

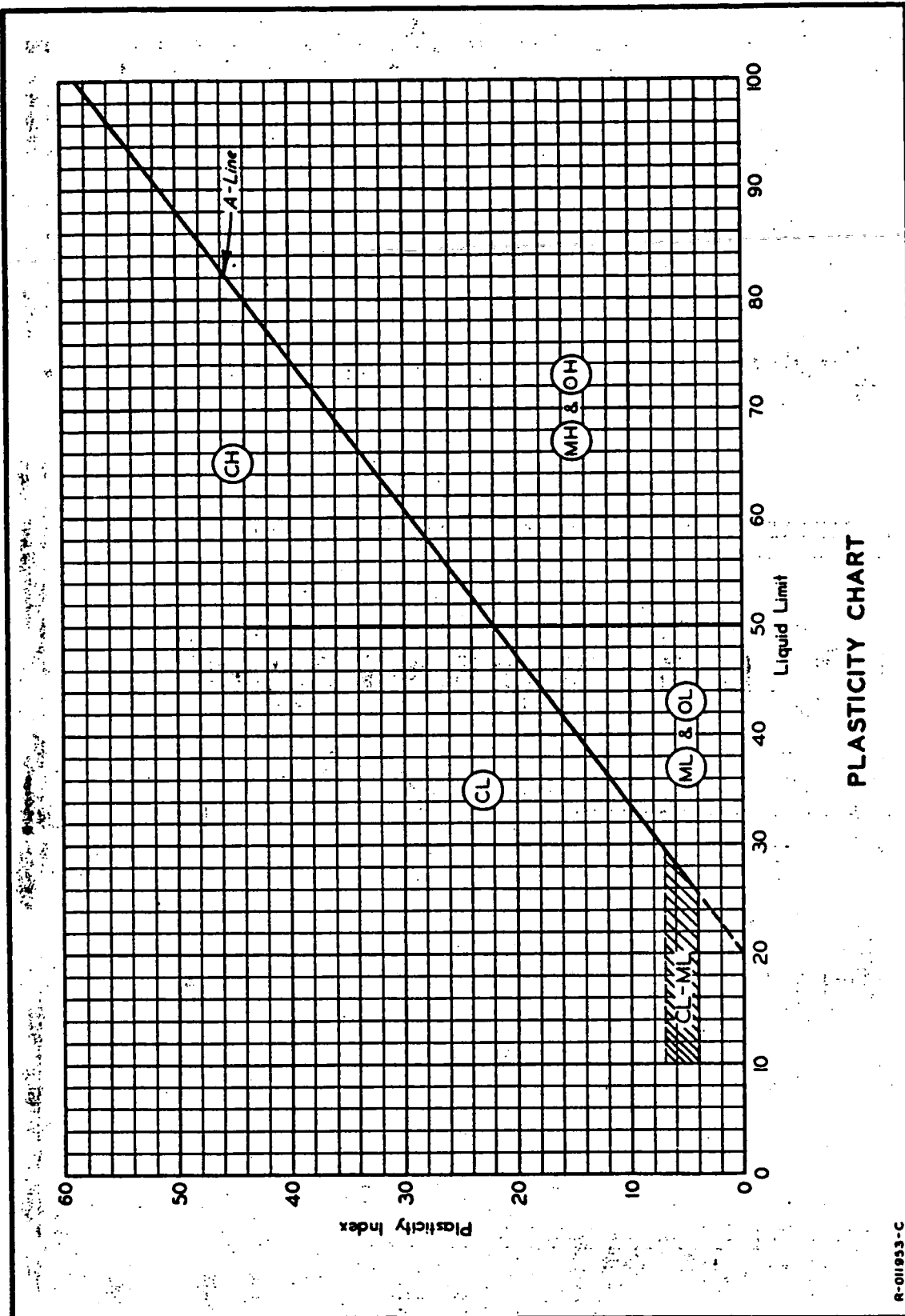
OL

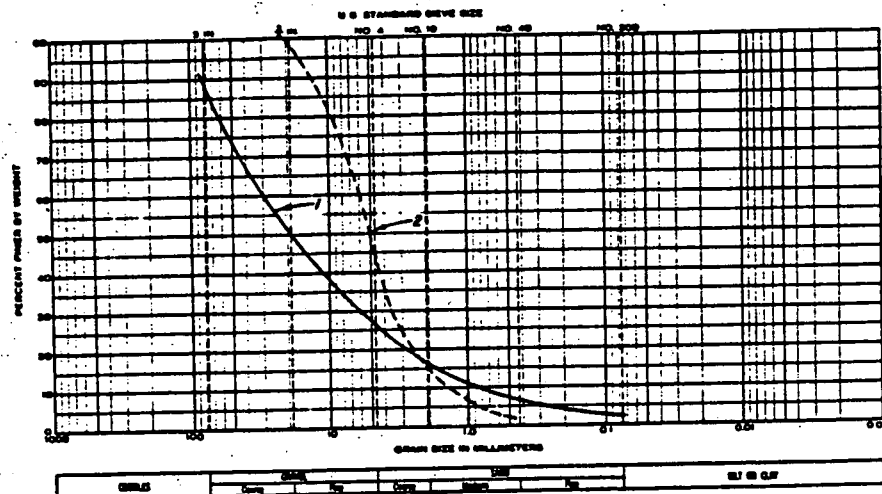
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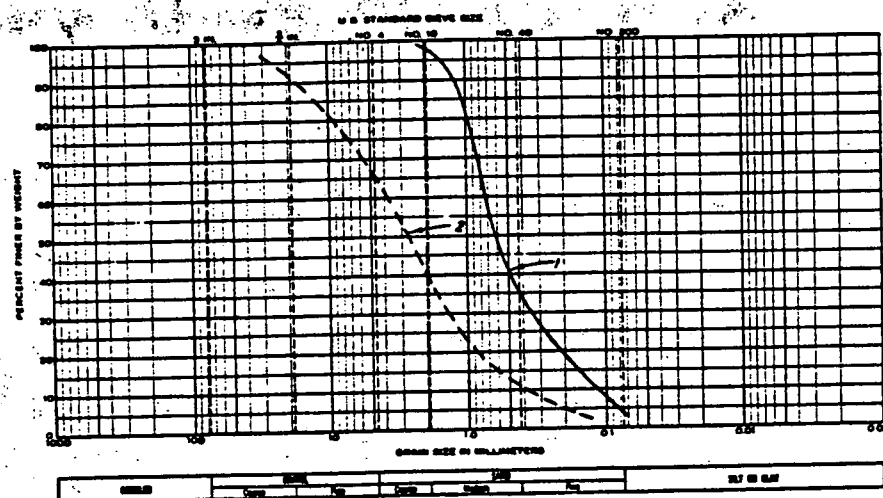
32-6





CURVE 1: Pit run gravel; nonplastic; well-graded; small percentage of fines.
 CURVE 2: Sandy gravel; nonplastic; no fines. Curve is about the steepest one that will meet the criteria for GW group.

GW GROUP
 FIG. 1

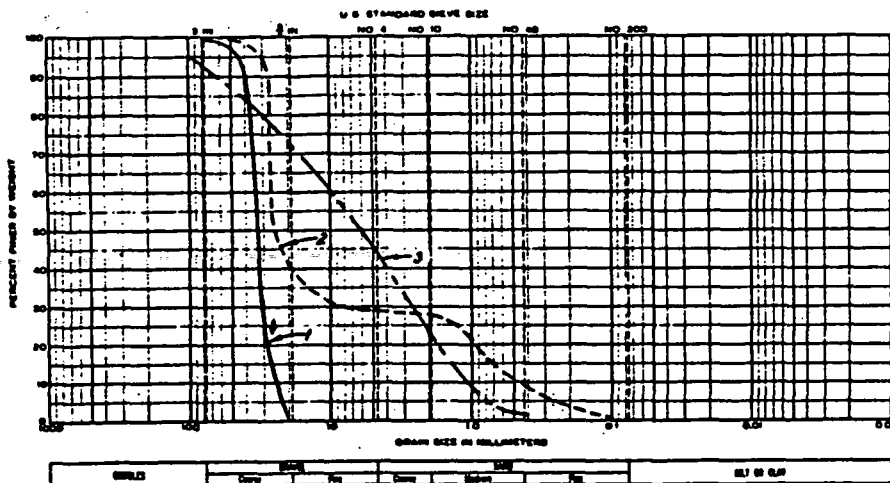


CURVE 1: Medium to fine sand; nonplastic; well-graded. Curve is about the steepest one that will meet the criteria for SW group.
 CURVE 2: Gravelly sand; nonplastic; well-graded.

SW GROUP
 FIG. 2

TYPICAL EXAMPLES
 GW AND SW SOILS

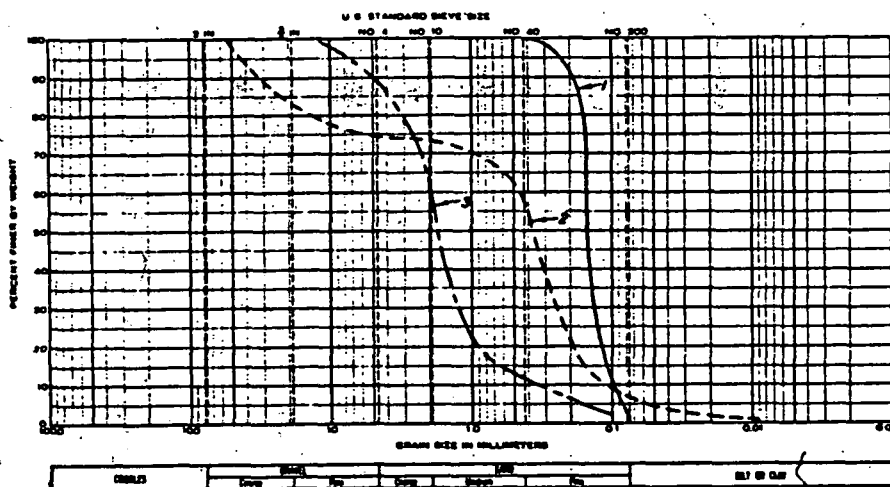
062652-A



- CURVE 1: Uniform coarse gravel; nonplastic. Very uniform gradation.
- CURVE 2: Gravel-sand mixture; nonplastic. Gravel is almost all of one size (3/4- to 1-in.), no fine gravel present. Poorly graded.
- CURVE 3: Sandy gravel; nonplastic. All sizes are present, but gradation does not meet curvature criterion for GW.

GP GROUP

FIG. 1



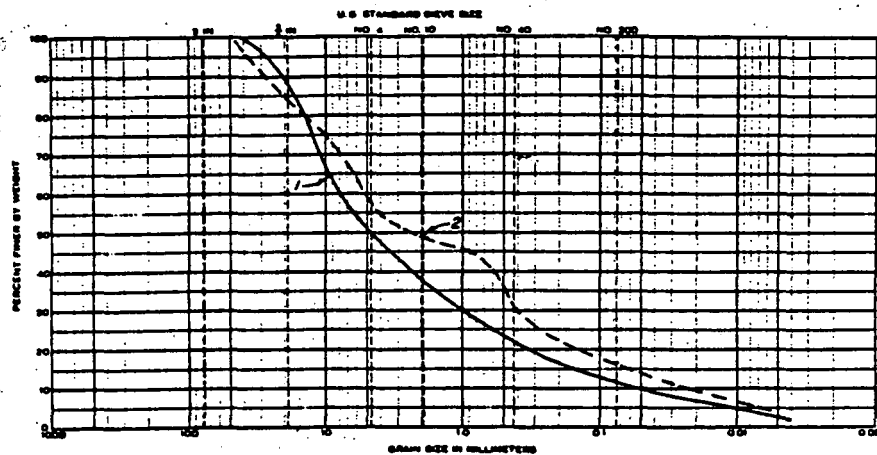
- CURVE 1: Uniform fine sand; nonplastic.
- CURVE 2: Poorly graded gravelly sand mixture; nonplastic. Approximately 7 per cent fines makes this a borderline soil, symbol SP-SM.
- CURVE 3: Coarse to medium sand; nonplastic. Approaching uniform gradation; does not meet curvature criterion for SW.

SP GROUP

FIG. 2

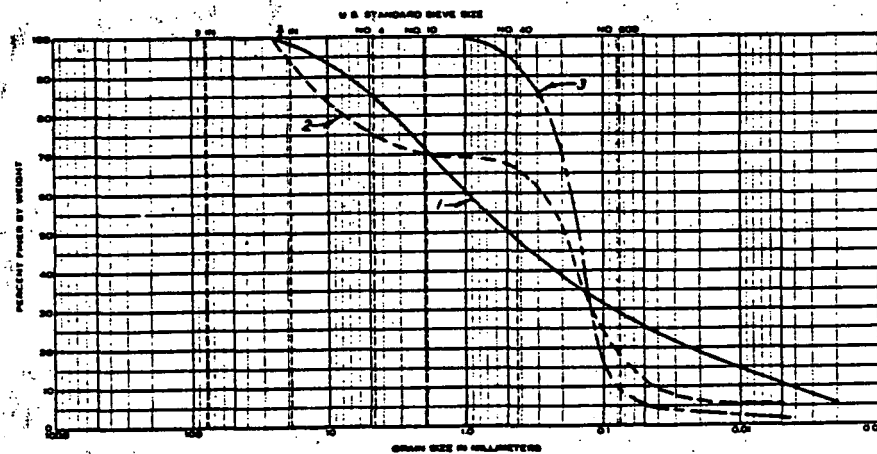
TYPICAL EXAMPLES GP AND SP SOILS

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CURVE 1: Crushed limestone; LL-16, PI-2. Well-graded. Made excellent base course material.
 CURVE 2: Gravel-sand-silt mixture; LL-32, PI-6. Poorly graded.

GM GROUP
FIG. 1

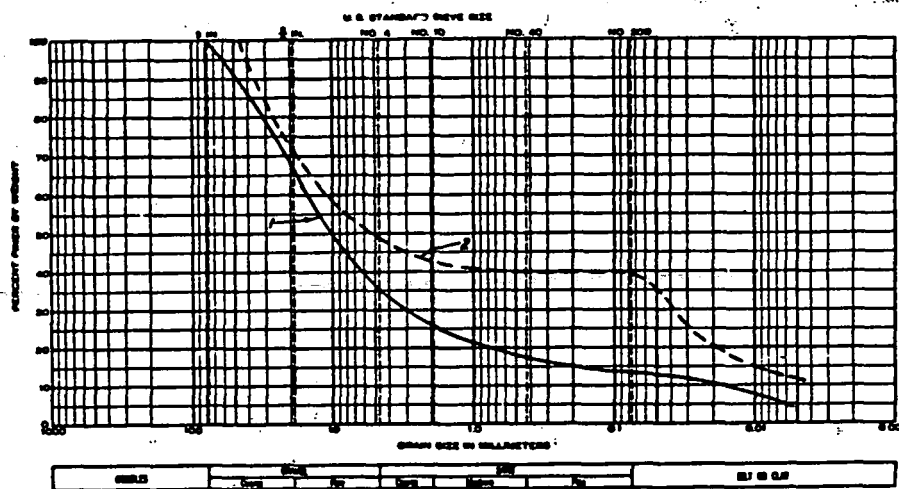


CURVE 1: Silty gravelly sand; nonplastic. Micaceous silt stabilized with sandy chert gravel.
 CURVE 2: Mixture of gravel-sand and fine silty sand; nonplastic. Poorly graded mixture; note absence of coarse and medium sand.
 CURVE 3: Silty fine sand; LL-22, PI-5. Uniform gradation, amount passing No. 200 sieve, and Atterberg limits classify soil as borderline in SP-SM-SC groups. Classify as SP-SM.

SM GROUP
FIG. 2

TYPICAL EXAMPLES GM AND SM SOILS

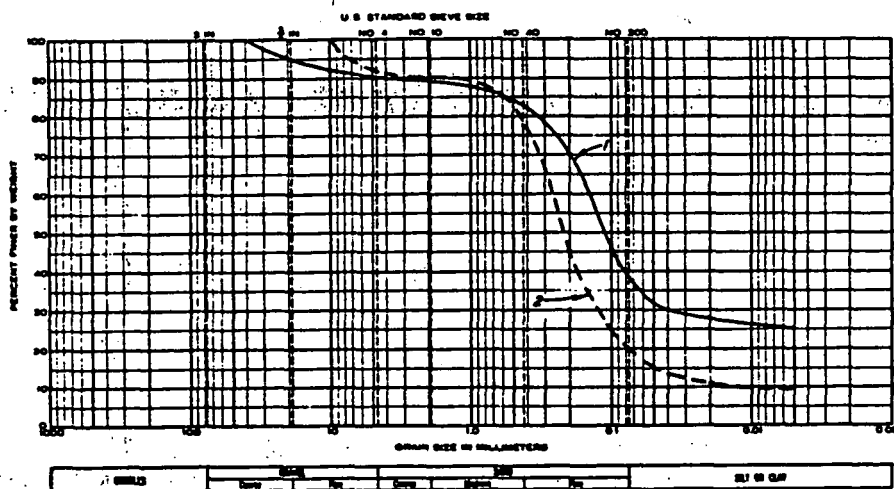
062652-C



CURVE 1: Clay-gravel (chart); LL-40, PI-19. Fairly low percentage of plastic fines.
 CURVE 2: Natural mixture of gravel and clay; LL-46, PI-20. Very poorly graded; almost no sand sizes present.

GC GROUP

FIG. 1



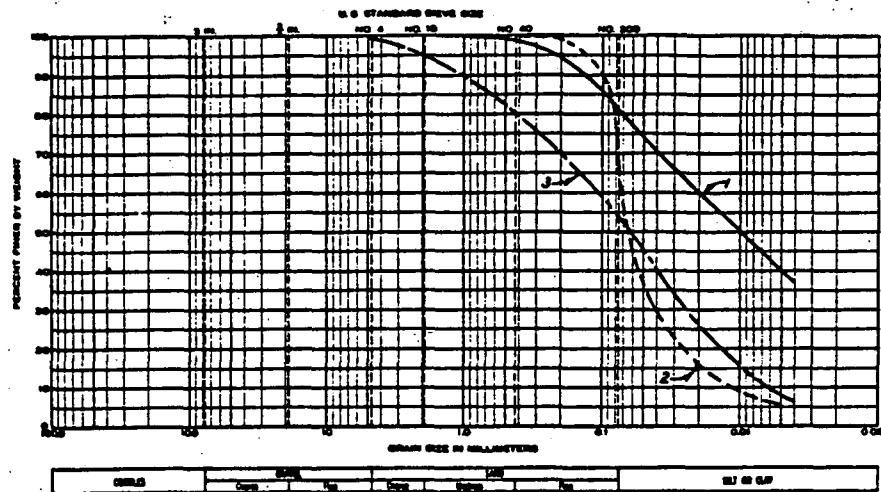
CURVE 1: Clayey sand; LL-23, PI-10. Poorly graded mixture of sand-clay and fine silty sand.
 CURVE 2: Limerock and sand mixture; LL-33, PI-8. Poorly graded.

SC GROUP

FIG. 2

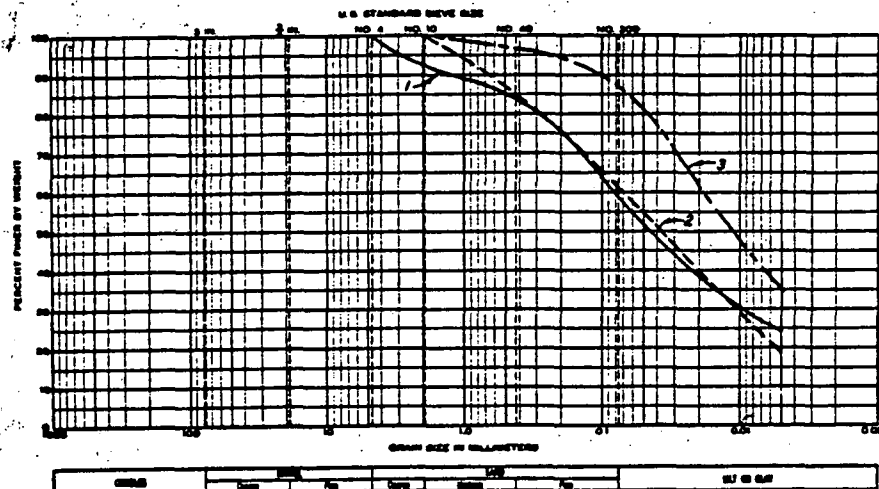
TYPICAL EXAMPLES
 GC AND SC SOILS

062652-0



CURVE 1: Clayey silt; LL-46, PI-16.
 CURVE 2: Uniform sandy silt; LL-30, PI-3.
 CURVE 3: Sandy silt; LL-34, PI-3.
 GENERAL: Note curves 2 and 3 have about the same plasticity but vary in grain size distribution.

ML GROUP
 FIG. 1

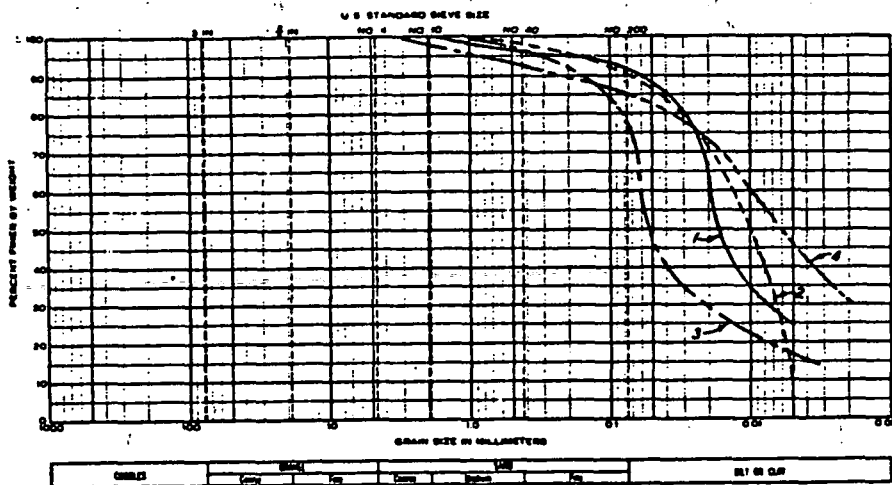


CURVE 1: Micaceous sandy silt; LL-55, PI-6.
 CURVE 2: Sandy silt; LL-67, PI-27.
 CURVE 3: Clayey silt; LL-54, PI-24.
 GENERAL: Note curves 1 and 2 have approximately the same grain size but are widely different in plasticity.

MH GROUP
 FIG. 2

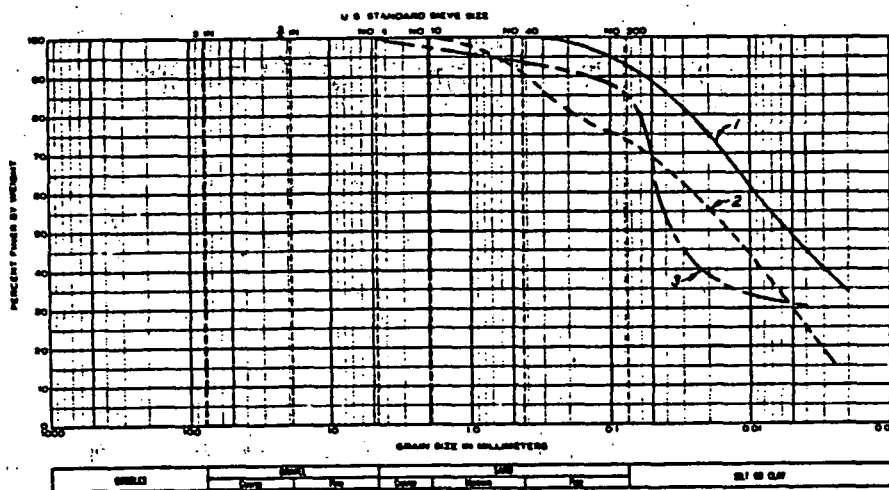
TYPICAL EXAMPLES
 ML AND MH SOILS

062682-C



CURVE 1: Lean clay; LL-30, PI-13.
 CURVE 2: Silty clay; LL-25, PI-6. Borderline, classify as CL-ML.
 CURVE 3: Sandy clay; LL-31, PI-18.
 CURVE 4: Clay; LL-44, PI-25.

CL GROUP
 FIG. 1

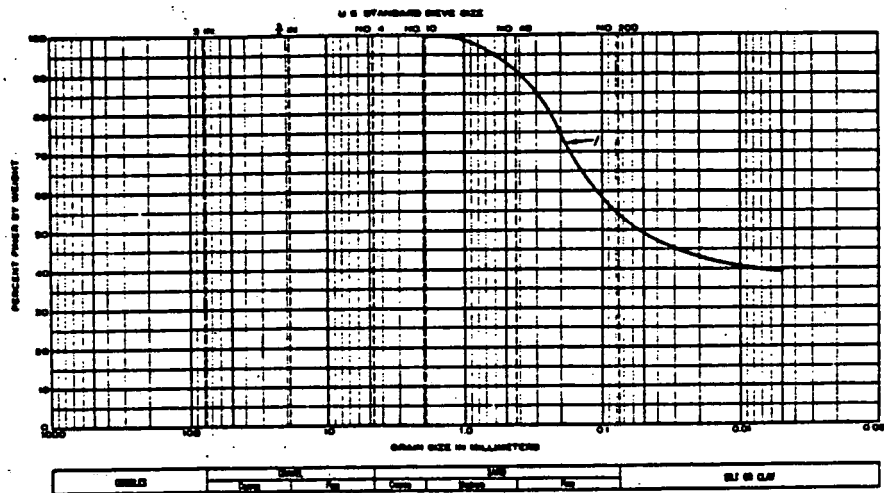


CURVE 1: Silty clay; LL-52, PI-25.
 CURVE 2: Sandy fat clay; LL-75, PI-45.
 CURVE 3: Sandy clay; LL-51, PI-29.

CH GROUP
 FIG. 2

TYPICAL EXAMPLES
 CL AND CH SOILS

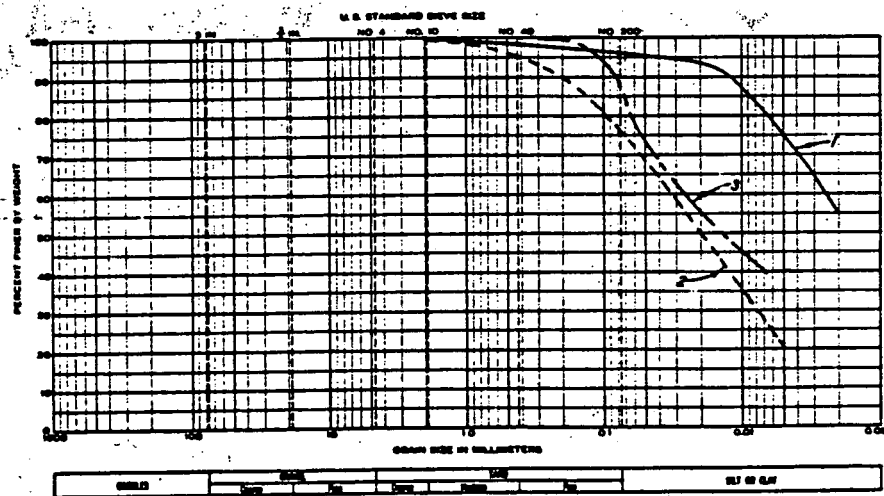
062652-F



CURVE 1: Organic sandy clay; LI-46, PI-15.

OL GROUP

FIG. 1



CURVE 1: Organic clay (tidal flats); LI-95, PI-39.
 CURVE 2: Alkali clay with organic matter; LI-66, PI-27.
 CURVE 3: Organic silt; LI-70, PI-33 (natural water content); LI-53, PI-19 (oven dried).

OH GROUP

FIG. 2

TYPICAL EXAMPLES
 OL AND OH SOILS

062052-G

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TECHNICAL MEMORANDUM NO. 3-357

APPENDIX A
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO
EMBANKMENTS AND FOUNDATIONS



March 1953

Sponsored by
Office, Chief of Engineers
U. S. Army

Conducted by
U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

Introduction

1. The major properties of a soil proposed for use in an embankment or foundation that are of concern to the design or construction engineer are its strength, permeability, and consolidation and compaction characteristics. Other features may be investigated for a specific problem, but in general some or all of the properties mentioned above are of primary importance in an earth embankment or foundation project of any magnitude. It is common practice to evaluate the properties of the soils in question by means of laboratory or field tests and to use the results of such tests as a basis for design and construction. The factors that influence strength, consolidation, and other characteristics are numerous and some of them are not completely understood; consequently, it is impractical to evaluate these features by means of a general soils classification. However, the soil groups in a given classification do have reasonably similar behavior characteristics, and while such information is not sufficient for design purposes, it will give the engineer an indication of the behavior of a soil when used as a component in construction. This is especially true in the preliminary examination for a project when neither time nor money for a detailed soils testing program is available.

2. It should be borne in mind by engineers using the classification

that only generalized characteristics of the soil groups are included therein, and they should be used primarily as a guide and not as the complete answer to a problem. For example, it is possible to design and construct an earth embankment of almost any type of soil and upon practically any foundation; this is in accordance with the worth-while principle of utilizing the materials available for construction. However, when a choice of materials is possible, certain of the available soils may be better suited to the job than others. It is on this basis that the behavior characteristics of soils are presented in the following paragraphs and on the classification sheet. The use to which a structure is to be put is often the principal deciding factor in the selection of soil types as well as the type of protective measures that will be utilized. Since each structure is a special problem within itself, it is impossible to cover all possible considerations in the brief description of pertinent soil characteristics contained in this appendix.

Features Shown on Soils Classification Sheet

3. General characteristics of the soil groups pertinent to embankments and foundations are presented in table A1. Columns 1 through 5 of the table show major soil divisions, group symbols, and hatching and color symbols; names of soil types are given in column 6. The basic features are the same as those presented in the soils classification manual. Columns 7 through 12 show the following: column 7, suitability of the materials for use in embankments (strength and permeability characteristics); column 8, the minimum or range of permeability values to be expected for the soil groups; columns 9 and 10, general compaction

characteristics; column 11, the suitability of the soils for foundations (strength and consolidation); and column 12, the requirements for seepage control, especially when the soils are encountered in the foundation for earth embankments (permeability). Brief discussions of these features are presented in the following paragraphs.

Suitability of soils for embankments

4. Three major factors that influence the suitability of soils for use in embankments are permeability, strength, and ease of compaction. The gravelly and sandy soils with little or no fines, groups GW, GP, SW, and SP, are stable, pervious, and attain good compaction with crawler-type tractors and rubber-tired rollers. The poorly-graded materials may not be quite as desirable as those which are well graded, but all of the materials are suitable for use in the pervious sections of earth embankments. Poorly-graded sands (SP) may be more difficult to utilize and, in general, should have flatter embankment slopes than the SW soils. The gravels and sands with fines, groups GM, GC, SM, and SC, have variable characteristics depending on the nature of the fine fraction and the gradation of the entire sample. These materials are often sufficiently impervious and stable to be used for impervious sections of embankments. The soils in these groups should be carefully examined to insure that they are properly zoned with relation to other materials in an embankment. Of the fine-grained soils, the CL group is best adapted for embankment construction; the soils are impervious, fairly stable, and give fair to good compaction with a sheepfoot roller or rubber-tired roller. The MH soils, while not desirable for rolled-fill construction, may be utilized in the core of hydraulic-fill structures. Soils of

the ML group may or may not have good compaction characteristics, and in general must be closely controlled in the field to secure the desired strength. CH soils have fair stability when used on flat slopes but have detrimental shrinkage characteristics which may necessitate blanketing them or incorporating them in thin interior cores of embankments. Soils containing organic matter, groups OL, OH, and Pt, are not commonly used for embankment construction because of the detrimental effects of the organic matter present. Such materials may often be utilized to advantage in blankets and stability berms where strength is not of importance.

Permeability and seepage control

5. Since the permeability (column 8) and requirements for seepage control (column 12) are essentially functions of the same property of a soil, they will be discussed jointly. The subject of seepage in relation to embankments and foundations may be roughly divided into three categories: (1) seepage through embankments; (2) seepage through foundations; and (3) control of uplift pressures. These are discussed in relation to the soil groups in the following paragraphs.

6. Seepage through embankments. In the control of seepage through embankments, it is the relative permeability of adjacent materials rather than the actual permeability of such soils that governs their use in a given location. An earth embankment is not watertight and the allowable quantity of seepage through it is largely governed by the use to which the structure is put; for example, in a flood-control project considerable seepage may be allowed and the structure will still fulfill the storage requirements, whereas for an irrigation project much less seepage is

allowable because pool levels must be maintained. The more impervious soils (GM, GC, SM, SC, CL, MH, and CH) may be used in core sections or in homogeneous embankments to retard the flow of water. Where it is important that seepage not emerge on the downstream slope or the possibility of drawdown exists on upstream slopes, more pervious materials are usually placed on the outer slopes. The coarse-grained, free-draining soils (GW, GP, SW, SP) are best suited for this purpose. Where a variety of materials is available they are usually graded from least pervious to more pervious from the center of the embankment outward. Care should be used in the arrangement of materials in the embankment to prevent piping within the section. The foregoing statements do not preclude the use of other arrangements of materials in embankments. Dams have been constructed successfully entirely of sand (SW, SP, SM) or of silt (ML) with the section made large enough to reduce seepage to an allowable value without the use of an impervious core. Coarse-grained soils are often used in drains and toe sections to collect seepage water in downstream sections of embankments. The soils used will depend largely upon the material that they drain; in general, free-draining sands (SW, SP) or gravels (GW, GP) are preferred, but a silty sand (SM) may effectively drain a clay (CL, CH) and be entirely satisfactory.

7. Seepage through foundations. As in the case of embankments, the use of the structure involved often determines the amount of seepage control necessary in foundations. Cases could be cited where the flow of water through a pervious foundation would not constitute an excessive water loss and no seepage control measures would be necessary if adequate provisions were made against piping in critical areas. If seepage control

is desired, then the more pervious soils are the soils in which necessary measures must be taken. Free-draining gravels (GW, GP) are capable of carrying considerable quantities of water, and some means of positive control such as a cutoff trench may be necessary. Clean sands (SW, SP) may be controlled by a cutoff or by an upstream impervious blanket.

While a drainage trench at the downstream toe or a line of relief wells will not reduce the amount of seepage, either will serve to control seepage and route the flow into collector systems where it can be led away harmlessly. Slightly less pervious material, such as silty gravels (GM), silty sands (SM), or silts (ML), may require a minor amount of seepage control such as that afforded by a toe trench, or if they are sufficiently impervious no control may be necessary. The relatively impervious soils (GC, SC, CL, OL, MH, CH, and OH) usually pass such a small volume of water that seepage control measures are not necessary.

8. Control of uplift pressures. The problem of control of uplift pressures is directly associated with pervious foundation soils. Uplift pressures may be reduced by lengthening the path of seepage (by a cutoff or upstream blanket) or by measures for pressure relief in the form of wells, drainage trenches, drainage blankets, or pervious downstream shells. Free-draining gravels (GW, GP) may be treated by any of the aforementioned procedures; however, to obtain the desired pressure relief, the use of a positive cutoff may be preferred, as blanket, well, or trench installations would probably have to be too extensive for economical accomplishment of the desired results. Free-draining sands (SW, SP) are generally less permeable than the gravels and, consequently, the volume of water that must be controlled for pressure relief is usually less.

Therefore a positive cutoff may not be required and an upstream blanket, wells, or a toe trench may be entirely effective. In some cases a combination of blanket and trench or wells may be desirable. Silty soils -- silty gravels (GM), silty sands (SM), and silts (ML) -- usually do not require extensive treatment; a toe drainage trench or well system may be sufficient to reduce uplift pressures. The more impervious silty materials may not be permeable enough to permit dangerous uplift pressures to develop and in such cases no treatment is indicated. In general, the more impervious soils (GC, SC, CL, OL, MH, CH, and OH) require no treatment for control of uplift pressures. However, they do assume importance when they occur as a relatively thin top stratum over more pervious materials. In such cases uplift pressures in the lower layers acting on the base of the impervious top stratum can cause heaving and formation of boils; treatment of the lower layer by some of the methods mentioned above is usually indicated in these cases. It is emphasized that control of uplift pressures should not be applied indiscriminately just because certain types of soils are encountered. Rather, the use of control measures should be based upon a careful evaluation of conditions that do or can exist, and an economical solution reached that will accomplish the desired results.

Compaction characteristics

9. In column 9 of the table are shown the general compaction characteristics of the various soil groups. The evaluations given and the equipment listed are based on average field conditions where proper moisture control and thickness of lift are attained and a reasonable number of passes of the compaction equipment is required to secure the

desired density. For lift construction of embankments, the sheepsfoot roller and rubber-tired roller are commonly used pieces of equipment. Some advantages may be claimed for the sheepsfoot roller in that it leaves a rough surface that affords better bond between lifts, and it kneads the soil thus affording better moisture distribution. Rubber-tired equipment referred to in the table is considered to be heavily loaded compactors or earth-moving equipment with a minimum wheel load of 15,000 lb. If ordinary wobble-wheel rollers are used for compaction, the thickness of compacted lift is usually reduced to about 2 in. Granular soils with little or no fines generally show good compaction characteristics, with the well-graded materials, GW and SW, usually furnishing better results than the poorly-graded soils, GP and SP. The sandy soils in most cases are best compacted by crawler-type tractors; on the gravelly materials rubber-tired equipment and sometimes steel-wheel rollers are also effective. Coarse-grained soils with fines of low plasticity, groups GM and SM, show good compaction characteristics with either sheepsfoot rollers or rubber-tired equipment; however, the range of moisture contents for effective compaction may be very narrow, and close moisture control is desirable. This is also generally true of the silty soils in the ML group. Soils of the ML group may be compacted with rubber-tired equipment or with sheepsfoot rollers. Gravels and sands with plastic fines, groups GC and SC, show fair compaction characteristics, although this quality may vary somewhat with the character and amount of fines; rubber-tired or sheepsfoot rollers may be used. Sheepsfoot rollers are generally used for compacting fine-grained soils. The compaction characteristics of such materials are variable -- lean clays and sandy clays

(CL) being the best, fat clays and lean organic clays or silts (OL and CH) fair to poor, and organic or micaceous soils (MH and OH) usually poor. For most construction projects of any magnitude it is highly desirable to investigate the compaction characteristics of the soil by means of a field test section. In column 10 of table A1 are shown ranges of unit dry weight of the soil groups for the standard AASHO (Proctor) compactive effort. It is emphasized that these values are for guidance only and design or construction control should be based on laboratory test results.

Suitability of soils for foundations

10. Suitability of soils for foundations of embankments or structures is primarily dependent on the strength and consolidation characteristics of the subsoils. Here again the type of structure and its use will largely govern the adaptability of a soil as a satisfactory foundation. For embankments, large settlements may be allowed and compensated for by overbuilding; whereas the allowable settlement of structures such as control towers, etc., may be small in order to prevent overstressing the concrete or steel of which they are built, or because of the necessity for adhering to established grades. Therefore a soil may be entirely satisfactory for one type of construction but may require special treatment for other types. Strength and settlement characteristics of soils are dependent upon a number of variables, such as structure, in-place density, moisture content, cycles of loading in their geologic history, etc., which are not readily evaluated by a classification system such as used here. For these reasons only very general statements can be made as to the suitability of the various soil types as foundations; this is especially true for fine-grained soils. In general, the gravels and

gravelly soils (GW, GP, GM, GC) have good bearing capacity and undergo little consolidation under load. Well-graded sands (SW) usually have a good bearing value. Poorly-graded sands and silty sands (SP, SM) may exhibit variable bearing capacity depending on their density; this is true to some extent for all the coarse-grained soils but is especially critical for uniformly graded soils of the SP and SM groups. Such soils when saturated may become "quick" and present an additional construction problem. Soils of the ML group may be subject to liquefaction and may have poor bearing capacity, particularly where heavy structure loads are involved. Of the fine-grained soils, the CL group is probably the best from a foundation standpoint, but in some cases the soils may be soft and wet and exhibit poor bearing capacity and fairly large settlements under load. Soils of the MH groups and normally-consolidated CH soils may show poor bearing capacity and large settlements. Organic soils, OL and OH, have poor bearing capacity and usually exhibit large settlement under load. For most of the fine-grained soils discussed above, the type of structure foundation selected is governed by such factors as the bearing capacity of the soil and the magnitude of the load. It is possible that simple spread footings might be adequate to carry the load without excessive settlement in many cases. If the soils are poor and structure loads are relatively heavy, then alternate methods are indicated. Pile foundations may be necessary in some cases and in special instances, particularly in the case of some CH and OH soils, it may be desirable and economically feasible to remove such soils from the foundation. Highly organic soils, Pt, generally are very poor foundation materials. These may be capable of carrying very light loads but in general are unsuited

for most construction purposes. If highly organic soils occur in the foundation, they may be removed if limited in extent, they may be displaced by dumping firmer soils on top, or piling may be driven through them to a stronger layer; proper treatment will depend upon the structure involved.

Graphical Presentation of Soils Data

11. It is customary to present the results of soils explorations on drawings or plans as schematic representations of the borings or test pits with the soils encountered shown by various symbols. Commonly used hatching symbols are small irregular round symbols for gravel, dots for sand, vertical lines for silts, and diagonal lines for clays. Combinations of these symbols represent various combinations of materials found in the explorations. This system has been adapted to the various soil groups in the unified soil classification system and the appropriate symbols are shown in column 4 of table A1. As an alternative to the hatching symbols, they may be omitted and the appropriate group letter symbol (CL, etc.) written in the boring log. In addition to the symbols on logs of borings, the effective size, D_{10} (grain size in mm corresponding to 10 per cent finer by weight), of coarse-grained soils and the natural water content of fine-grained soils should be shown by the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain special instances the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of table A1.

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Table A1

CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

Major Divisions (1)	Letter (2)	Symbol		Name (6)	Value for Embankments (7)	Permeability cm Per Sec (8)	Compaction Characteristics (9)	Std ASTM Max Unit Dry Weight lb Per Cu Ft (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
		Hatching (3)	Color (5)							
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GM	Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	125-135	Good bearing value	Positive cutoff
		GP		Poorly-graded gravels or gravel-sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	115-125	Good bearing value	Positive cutoff
		GM	Yellow	Silty gravels, gravel-sand-silt mixtures	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepfoot roller	120-135	Good bearing value	Toe trench to some
		GC		Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepfoot roller	115-130	Good bearing value	None
	SAND AND SANDY SOILS	SW	Red	Well-graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Good bearing value	Upstream blanket and toe drainage or wells
		SP		Poorly-graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SM	Yellow	Silty sands, sand-silt mixtures	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepfoot roller	110-125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SC		Clayey sands, sand-silt mixtures	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepfoot roller, rubber tired	105-125	Good to poor bearing value	None
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML	Green	Inorganic silt and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepfoot roller	95-120	Very poor, susceptible to liquefaction	Toe trench to some
		CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepfoot roller, rubber tired	95-120	Good to poor bearing	None
		OL		Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepfoot roller	80-100	Fair to poor bearing, may have excessive settlements	None
	SILTS AND CLAYS LL > 50	MH	Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepfoot roller	70-95	Poor bearing	None
		CH		Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepfoot roller	75-105	Fair to poor bearing	None
		OH		Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepfoot roller	65-100	Very poor bearing	None
	HIGHLY ORGANIC SOILS	PT	Orange	Peat and other highly organic soils	Not used for construction		Compaction not practical		Remove from foundations	

Notes: 1. Values in columns 7 and 11 are for guidance only. Design should be based on test results.

2. In column 9, the equipment listed will usually produce the desired densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled.

3. Column 10, unit dry weights are for compacted soil at optimum moisture content for Standard ASTM (Standard Proctor) compactive effort.

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APPENDIX B
UNIFIED SOIL CLASSIFICATION SYSTEM
CHARACTERISTICS OF SOIL GROUPS
PERTAINING TO ROADS AND AIRFIELDS

UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

Introduction

1. The properties desired in soils for foundations under roads and airfields and for base courses under flexible pavements are: adequate strength, good compaction characteristics, adequate drainage, resistance to frost action in areas where frost is a factor, and acceptable compression and expansion characteristics. Certain of these properties, if inadequate in the soils available, may be supplied by proper construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water collecting system. Strength requirements for base course materials, to be used immediately under the pavement of a flexible pavement structure, are high and only good quality materials are acceptable. However, low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying concrete pavement or of base materials in flexible pavement construction. From the foregoing brief discussion, it may be seen that the proper design of roads and airfield pavements requires the evaluation of soil properties in more detail than is possible by use of the general soils classification system. However, the grouping of soils in the classification system is such that a general indication of their behavior in road and airfield construction may be obtained.

Features Shown on Soils Classification Sheet

2. General characteristics of the soil groups pertinent to roads and airfields are presented in table B1. Columns 1 through 5 show major

soil divisions, group symbols, hatching and color symbols; column 6 gives names of soil types; column 7 evaluates the performance (strength) of the soil groups when used as subgrade materials that will not be subject to frost action; column 8 and column 9 make a similar evaluation for the soils when used as subbase and base materials; potential frost action is shown in column 10; compressibility and expansion characteristics are shown in column 11; column 12 presents drainage characteristics; column 13 shows types of compaction equipment that perform satisfactorily on the various soil groups; column 14 shows ranges of unit dry weight for compacted soils; column 15 gives ranges of typical California Bearing Ratio (CBR) values; and column 16 gives ranges of modulus of subgrade reaction (k). The various features presented are discussed in the following paragraphs.

Subdivision of coarse-grained soil groups

3. It will be noted in column 3, letter symbols, that the basic soil groups, GM and SM, have each been subdivided into two groups designated by the suffixes d and u which have been chosen to represent desirable and less desirable (undesirable) base materials, respectively. This subdivision applies to roads and airfields only and is based on field observation and laboratory tests on the behavior of the soils in these groups. Basis for the subdivision is the liquid limit and plasticity index of the fraction of the soil passing the No. 40 sieve. The suffix d is used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u is used otherwise. Typical symbols for soils in these groups are GMd and SMu, etc.

Values of soils as subgrade, subbase, or base materials

4. The descriptions in columns 7, 8, and 9 give a general indication of the suitability of the soil groups for use as subgrades, subbase, or base materials, provided they are not subject to frost action. In areas where frost heaving is a problem, the value of materials as subgrades or subbases will be reduced, depending on the potential frost action of the material, as shown in column 10. Proper design procedures

should be used in situations where this is a problem. The coarse-grained soils in general are the best subgrade, subbase, and base materials. The GW group has excellent qualities as a subgrade and subbase, and is good as base material. It is noted that the adjective "excellent" is not used for any of the soils for base courses; it is considered that the adjective "excellent" should be used in reference to a high quality processed crushed stone. Poorly-graded gravels and some silty gravels, groups GP and GMd, are usually only slightly less desirable as subgrade or subbase materials, and under favorable conditions may be used as base materials for certain conditions; however, poor gradation and other factors sometimes reduce the value of such soils to such extent that they offer only moderate strength and therefore their value as a base material is less. The GMu, GC, and SW groups are reasonably good subgrade materials, but are generally poor to not suitable as bases. The SP and SMd soils usually are considered fair to good subgrade and subbase materials but in general are poor to not suitable for base materials. The SMu and SC soils are fair to poor subgrade and subbase materials, and are not suitable for base materials. The fine-grained soils range from fair to very poor subgrade materials as follows: silts and lean clays (ML and CL), fair to poor; organic silts, lean organic clays, and micaceous or diatomaceous soils (OL and MH), poor; fat clays and fat organic clays (CH and OH), poor to very poor. These qualities are compensated for in flexible pavement design by increasing the thickness of overlying base material, and in rigid pavement design by increasing the pavement thickness or by the addition of a base course layer. None of the fine-grained soils are suitable as subbase or base materials. The fibrous organic soils (group Pt) are very poor subgrade materials and should be removed wherever possible; otherwise, special construction measures should be adopted. They are not suitable as subbase and base materials. The California Bearing Ratio (CBR) values shown in column 15 give a relative indication of the strength of the various soil groups as used in flexible pavement design. Similarly, values of subgrade modulus (k) in column 16 are relative indications of strengths from plate-bearing tests as used in rigid pavement design. As these tests are used for the design of pavements, actual

test values should be used for this purpose instead of the approximate values shown in the tabulation.

5. For wearing surfaces on unsurfaced roads sand-clay-gravel mixtures (GC) are generally considered the most satisfactory. However, they should not contain too large a percentage of fines and the plasticity index should be in the range of 5 to about 15.

Potential frost action

6. The relative effects of frost action on the various soil groups are shown in column 10. Regardless of the frost susceptibility of the various soil groups two conditions must be present simultaneously before frost action will be a major consideration. These are a source of water during the freezing period and a sufficient period for the freezing temperature to penetrate the ground. Water necessary for the formation of ice lenses may become available from a high ground-water table, capillary supply, water held within the soil voids, or through infiltration. The degree of ice formation that will occur in any given case is markedly influenced by environmental factors such as topographic position, stratification of the parent soil, transitions into cut sections, lateral flow of water from side cuts, localized pockets of perched ground water, and drainage conditions. In general, the silts and fine silty sands are the worst offenders as far as frost is concerned. Coarse-grained materials with little or no fines are affected only slightly if at all. Clays (CL and CH) are subject to frost action, but the loss of strength of such materials may not be as great as for silty soils. Inorganic soils containing less than three per cent of grains finer than 0.02 mm in diameter by weight are generally nonfrost-susceptible. Where frost-susceptible soils are encountered in subgrades and frost is a definite problem, two acceptable methods of design of pavements are available. Either a sufficient depth of acceptable granular material is placed over the soils to prevent freezing in the subgrade and thereby prevent the detrimental effects of frost action, or a reduced depth of granular material is used, thereby allowing freezing in the subgrade, and design is based on the reduced strength of the subgrade during the frost-melting period. In many cases appropriate drainage measures to prevent the accumulation of

water in the soil pores will help to diminish ice segregation in the subgrade and subbase.

Compressibility and expansion

7. These characteristics of soils may be of two types insofar as their applicability to road and runway design is concerned. The first is the relatively long-term compression or consolidation under the dead weight of the structure, and the second is the short-term compression and rebound under moving wheel loads. The long-term consolidation of soils becomes a factor in design primarily when heavy fills are made on compressible soils. If adequate provision is made for this type of settlement during construction it will have little influence on the load-carrying capacity of the pavement. However, when elastic soils subject to compression and rebound under wheel load are encountered, adequate protection must be provided, as even small movements of this type soil may be detrimental to the base and wearing course of pavements. It is fortunate that the free-draining, coarse-grained soils (GW, GP, SW, and SP), which in general make the best subgrade and subbase materials, exhibit almost no tendency toward high compressibility or expansion. In general, the compressibility of soils increases with increasing liquid limit. The foregoing is not completely true, as compressibility is also influenced by soil structure, grain shape, previous loading history, and other factors that are not evaluated in the classification system. Undesirable compressibility or expansion characteristics may be reduced by distribution of load through a greater thickness of overlying material. This, in general, is adequately handled by the CBR method of design for flexible pavements; however, rigid pavements may require the addition of an acceptable base course under the pavement.

Drainage characteristics

8. The drainage characteristics of soils are a direct reflection of their permeability. The evaluation of drainage characteristics for use in roads and runways is shown in column 12. The presence of moisture in base, subbase, and subgrade materials, except for free-draining, coarse-grained soils, may cause the development of pore water pressures and loss of strength. The moisture may come from infiltration of rain water or by

capillary rise from an underlying water table. While free-draining materials permit rapid draining of water, they permit rapid ingress of water also, and if such materials are adjacent to less pervious materials and have free access to water they may serve as reservoirs to saturate the less pervious materials. It is obvious, therefore, that in most instances adequate drainage systems should be provided. The gravelly and sandy soils with little or no fines (groups GW, GP, SW, and SP) have excellent drainage characteristics. The GMd and SMd groups have fair to poor drainage characteristics, whereas the GMu, GC, SMu, and SC groups may be practically impervious. Soils of the ML, MH, and Pt groups have fair to poor drainage characteristics. All of the other groups have poor drainage characteristics or are practically impervious.

Compaction equipment

9. The compaction of soils for roads and runways, especially for the latter, requires that a high degree of density be attained at the time of construction in order that detrimental consolidation will not take place under traffic. In addition, the detrimental effects of water are lessened in cases where saturation or near saturation takes place. Processed materials, such as crushed rock, are often used as base course and such materials require special treatment in compaction. Types of compaction equipment that will usually produce the desired densities are shown in column 13. It may be noted that several types of equipment are listed for some of the soil groups; this is because variations in soil type within a given group may require the use of different equipment. In some cases more than one type of equipment may be necessary to produce the desired densities. Steel-wheeled rollers are recommended for angular materials with limited amounts of fines, crawler-type tractors or rubber-tired rollers for gravels and sands, and sheepfoot rollers for coarse-grained or fine-grained soils having some cohesive qualities. Rubber-tired rollers are also recommended for final compaction operations for most soils except those of high liquid limit (group H). Suggested minimum weights of the various types of equipment are shown in note 2 of the table. In column 14 are shown ranges of unit dry weight for soils compacted according to test method 100 (CE 55 compaction effort),

MIL-STD-621A. These values are included primarily for guidance; design or control of construction should be based on test results.

Graphical Presentation of Soils Data

10. It is customary to present the results of soils explorations on drawings as schematic representations of the borings or test pits or on soil profiles with the various soils encountered shown by appropriate symbols. As one approach, the group letter symbol (CL, etc.) may be written in the appropriate section of the log. As an alternative, hatching symbols shown in column 4 of table B1 may be used. In addition, the natural water content of fine-grained soils should be shown along the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain special instances the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of table B1.



Standard Method for Particle-Size Analysis of Soils¹

This standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

^{e1} NOTE—Section 2 was added editorially and subsequent sections renumbered in July 1984.

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425- μm), or No. 200 (75- μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (1) a high-speed mechanical stirrer, and (2) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20- μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm .

2. Referenced Documents

2.1 ASTM Standards:

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants²

E 11 Specification for Wire-Cloth Sieves for Testing Purposes³

E 100 Specification for ASTM Hydrometers⁴

3. Apparatus

3.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 *Stirring Apparatus*—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a

replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than 3/4 in. (19.0 mm) nor more than 1 1/2 in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup⁵ (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft³/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2 1/2 in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 \pm 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

¹ This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

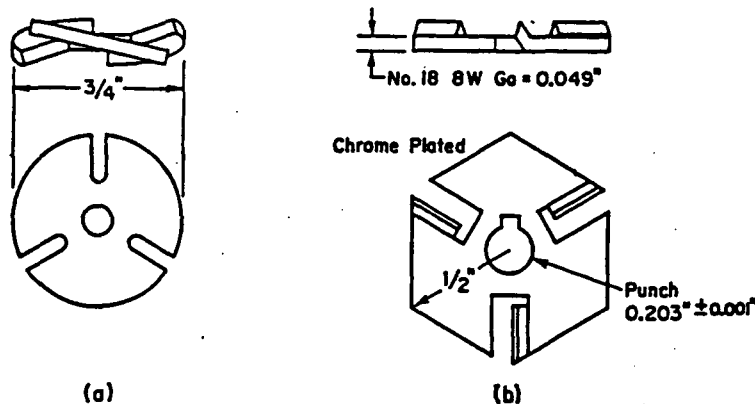
Current edition approved Nov. 21, 1963. Originally published 1935. Replaces D 422 - 62.

² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 14.02.

⁴ Annual Book of ASTM Standards, Vol 14.01.

⁵ Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Order Adjunct No. 12-404220-00.



Metric Equivalents					
in.	0.001	0.049	0.203	1/2	3/4
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles

- | | |
|---------------------|------------------|
| 3-in. (75-mm) | No. 10 (2.00-mm) |
| 2-in. (50-mm) | No. 20 (850-μm) |
| 1 1/2-in. (37.5-mm) | No. 40 (425-μm) |
| 1-in. (25.0-mm) | No. 60 (250-μm) |
| 3/4-in. (19.0-mm) | No. 140 (106-μm) |
| 1/2-in. (9.5-mm) | No. 200 (75-μm) |
| No. 4 (4.75-mm) | |

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

- | | |
|---------------------|------------------|
| 3-in. (75-mm) | No. 16 (1.18-mm) |
| 1 1/2-in. (37.5-mm) | No. 30 (600-μm) |
| 3/4-in. (19.0-mm) | No. 50 (300-μm) |
| 1/2-in. (9.5-mm) | No. 100 (150-μm) |
| No. 4 (4.75-mm) | No. 200 (75-μm) |
| No. 8 (2.36-mm) | |

3.7 Water Bath or Constant-Temperature Room—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

3.8 Beaker—A beaker of 250-mL capacity.

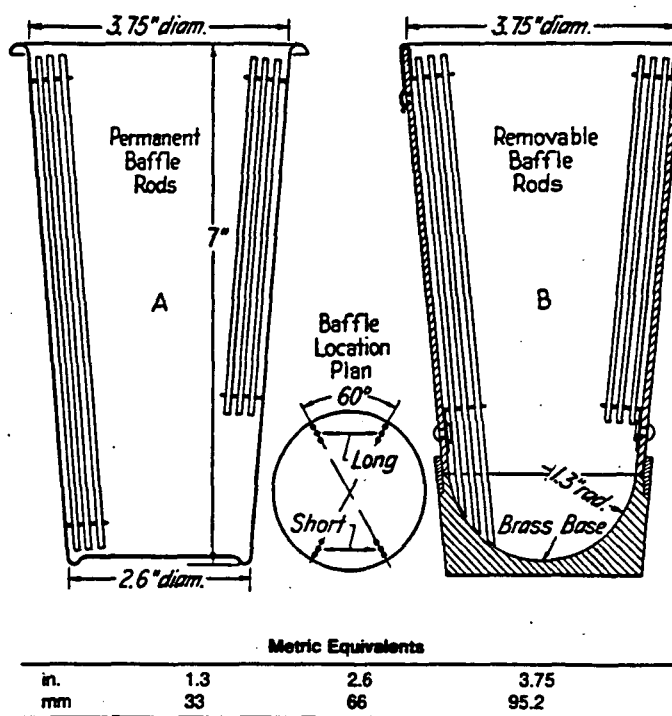
3.9 Timing Device—A watch or clock with a second hand.

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall



Metric Equivalents			
in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus

be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

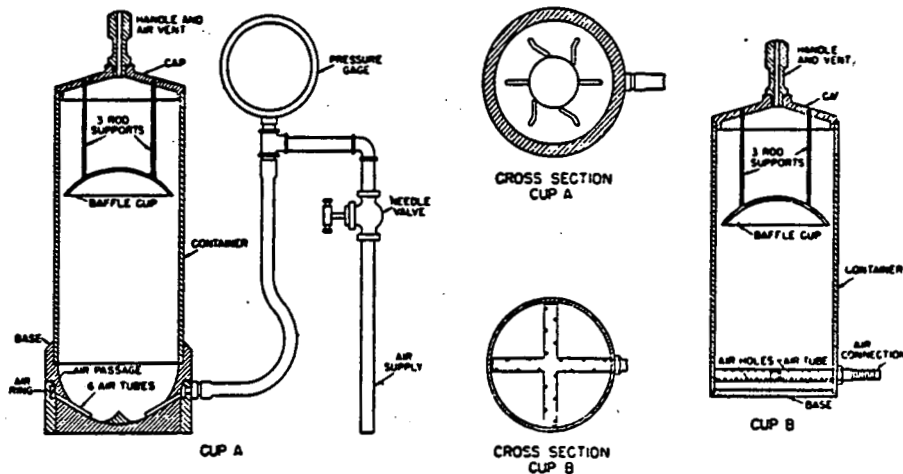


FIG. 3 Air-Jet Dispersion Cups of Apparatus B

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
3/8 (9.5)	500
1/4 (19.0)	1000
1 (25.4)	2000
1 1/2 (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

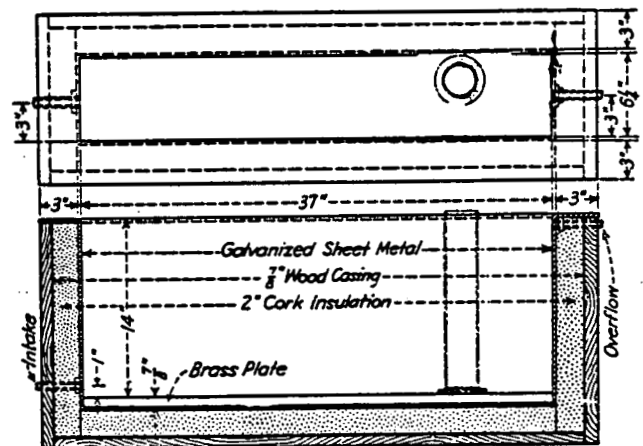
5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm),



Metric Equivalents						
in.	7/8	1	3	6 1/4	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

2-in. (50-mm), 1 1/2-in. (37.5-mm), 1-in. (25.0-mm), 3/4-in. (19.0-mm), 3/8-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns.

Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75- μ m) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the $\frac{1}{8}$ -in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the $\frac{1}{8}$ -in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

TABLE 1 Values of Correction Factor, α , for Different Specific Gravities of Soil Particles^A

Specific Gravity	Correction Factor ^A
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

^A For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

α = correction factor to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading with composite correction applied (Section 7),

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,

G = specific gravity of the soil particles, and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1 .

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30\pi/980(G - G_1)] \times L/T}$$

where:

D = diameter of particle, mm.

n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2)).

T = interval of time from beginning of sedimentation to the taking of the reading, min.

G = specific gravity of soil particles, and

G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A - and B -scales, the square root being indicated on the D -scale. Without ascertaining the value of the square root it may be multiplied by K , using either the C - or CI -scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes^a

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	18.3	0	18.3	31	11.2
1.001	18.0	1	18.1	32	11.1
1.002	15.8	2	18.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

^a Values of effective depth are calculated from the equation:

$$L = L_1 + \frac{1}{2} [L_2 - (V_0/A)]$$

where:

L = effective depth, cm.

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm.

L_2 = overall length of the hydrometer bulb, cm.

V_0 = volume of hydrometer bulb, cm³, and

A = cross-sectional area of sedimentation cylinder, cm²

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

L_2 = 14.0 cm

V_0 = 67.0 cm³

A = 27.8 cm²

For hydrometer 151H:

L_1 = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

17. Graph

17.1 When the hydrometer analysis is performed, a graph

TABLE 3 Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.1323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed

almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

- | | |
|--|---------|
| (1) Gravel, passing 3-in. and retained on No. 4 sieve | % |
| (2) Sand, passing No. 4 sieve and retained on No. 200 sieve | % |
| (a) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve | % |
| (b) Medium sand, passing No. 10 sieve and retained on No. 40 sieve | % |
| (c) Fine sand, passing No. 40 sieve and retained on No. 200 sieve | % |
| (3) Silt size, 0.074 to 0.005 mm | % |
| (4) Clay size, smaller than 0.005 mm | % |
| Colloids, smaller than 0.001 mm | % |

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.
2-in.
1½-in.
1-in.
¾-in.
½-in.
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-µm)
No. 200 (75-µm)

HYDROMETER ANALYSIS

0.074 mm
0.005 mm
0.001 mm

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-µm) sieves may be substituted for No. 10 and No. 40 sieves.

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Character:

Major Divisions (1)	Symbol (2)	Letter (3)	Matching (4)	Color (5)	Name (6)	Value as Subgrade When Not Subject to Frost Action (7)	Value as Subgrade When Not Subject to Frost Action (8)
COARSE- GRADED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good
		GM		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good
		GU		Yellow		Good	Fair
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Fair
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to good
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair
		SM		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to good
		SU		Yellow		Fair	Poor to fair
		SC		Yellow	Clayey sands, sand-clay mixtures	Poor to fair	Poor
FINE- GRADED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor to fair	Not suitable
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitable
		OL		Green	Organic silts and organic silt-clays of low plasticity	Poor	Not suitable
	SILTS AND CLAYS LL IS GREATER THAN 50	ME		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable
		CH		Blue	Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitable
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable
		Pe		Orange	Peat and other highly organic soils	Not suitable	Not suitable

Note:

- Column 3, division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is on basis of plasticity index is 5 or less; the suffix u will be used otherwise.
- In column 13, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of equipment may be required.
 - Processed base materials and other angular materials. Steel-wheeled and rubber-tired rollers are recommended for hard, angular materials subject to degradation.
 - Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materials.
 - Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:
 - Crawler-type tractor -- total weight in excess of 30,000 lb.
 - Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain the required densities.
 - Sheepfoot roller -- unit pressure (on 6- to 12-sq.-in. foot) to be in excess of 250 psi and unit pressures as high as 650 psi may be at least 5 per cent of the total peripheral area of the drum, using the diameter measured to the face of the feet.
- Column 14, unit dry weights are for compacted soil at optimum moisture content for modified AASHTO compaction effort (CB 55).
- In column 15, the maximum value that can be used in design of airfields is, in some cases, limited by gradation and plasticity requirements.

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Table E1

Characteristics Pertinent to Roads and Airfields

	Value as Subgrade When Not Subject to Frost Action (7)	Value as Subbase When Not Subject to Frost Action (8)	Value as Base When Not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	
and	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawle roller
and	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawle roller
mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber roller
	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber roller
y mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber roller
ands,	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawle roller
	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawle roller
	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor	Rubber roller moist.
	Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber roller
e	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber roller
ands, rock ds or city	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber roller
m plastic- e, silty	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber roller
-clays of	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber roller
liatomaceous tic silts	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheeps roller
ity, fat	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheeps roller
s	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheeps roller
soils	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compac

and airfields only. Subdivision is on basis of Atterberg limits; suffix d (e.g., GMD) will be used when the liquid limit is 25 or less and the reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment different equipment. In some instances, a combination of two types may be necessary.

red rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer materials.

operations for most soils and processed materials.

densities required for airfield construction:

as 40,000 lb may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 psi). 250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials. The area of the feet should be measured to the center of the feet.

ified AASHTO compaction effort (CE 75).

uses, limited by gradation and plasticity requirements.

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4 Airfields

Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	Compaction Equipment (13)	Unit Dry Weight lb per cu ft (14)	Typical Design Values	
					CBR (15)	Subgrade Modulus k lb per cu in. (16)
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125-140	40-80	300-500
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110-140	30-60	300-500
Slight to medium	Very slight	Fair to poor	Rubber-tired roller, sheepfoot roller; close control of moisture	125-145	40-60	300-500
Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	115-135	20-30	200-500
Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	130-145	20-40	200-500
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110-130	20-40	200-400
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105-135	10-40	150-400
Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheepfoot roller; close control of moisture	120-135	15-40	150-400
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	100-130	10-20	100-300
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepfoot roller	100-135	5-20	100-300
Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheepfoot roller; close control of moisture	90-130	15 or less	100-200
Medium to high	Medium	Practically impervious	Rubber-tired roller, sheepfoot roller	90-130	15 or less	50-150
Medium to high	Medium to high	Poor	Rubber-tired roller, sheepfoot roller	90-105	5 or less	50-100
Medium to very high	High	Fair to poor	Sheepfoot roller, rubber-tired roller	80-105	10 or less	50-100
Medium	High	Practically impervious	Sheepfoot roller, rubber-tired roller	90-115	15 or less	50-150
Medium	High	Practically impervious	Sheepfoot roller, rubber-tired roller	80-110	5 or less	25-100
Slight	Very high	Fair to poor	Compaction not practical	-	-	-

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(e.g., GMA) will be used when the liquid limit is 25 or less and the re properly controlled. In some instances, several types of equipment necessary. e screenings. Rubber-tired equipment is recommended for softer materials

erials (based on contact pressure of approximately 65 to 150 psi). required densities for some materials. The area of the feet should

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February 18, 1991
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TITLE:
DRILLING AND SAMPLING USING
HOLLOW STEM AUGER TECHNIQUES

Approved By:

J. W. Langman

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for drilling and obtaining samples of soil and rock from hollow-stem auger borings. In general, hollow-stem auger coring will be the preferred technique for obtaining environmental samples of subsoil and bedrock from boreholes at the RFP. Other types of samples may also be obtained from hollow-stem auger borings. This SOP describes hollow-stem auger drilling and sampling equipment and procedures, and decontamination that will be used for field data collection and documentation in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing drilling operations and logging alluvial and bedrock materials should be geologists with a minimum of a B.S. or B.A. degree in geology and have applicable field experience. Other qualified personnel may include geotechnical engineers or field technicians with an appropriate amount of field experience or on-the-job training under supervision of another qualified person. The personnel will be trained to log according to the RFP "reference" cores and samples (see SOP 3.1, *Logging Alluvial and Bedrock Material*).

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

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Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1. September, 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 1.4, Heavy Equipment Decontamination
- SOP 1.8, Handling of Drilling Fluids and Cuttings
- SOP 1.9, Handling of Residual Samples
- SOP 3.1, Logging Alluvial and Bedrock Material
- SOP 3.3, Isolating Bedrock from Alluvium with Grouted Surface Casing
- SOP 3.4, Rotary Drilling and Rock Coring
- SOP 3.5, Plugging and Abandonment of Boreholes
- SOP 3.6, Monitoring Well and Piezometer Installation
- SOP 3.10, Borehole Clearing

5.0 PROCEDURES FOR DRILLING AND SAMPLING

Hollow-stem augers are one type of continuous-flight auger used for advancing boreholes when discrete samples of the subsurface materials are obtained. They are particularly applicable for sampling materials with a tendency to cave in and for environmental sampling. The augers consist

of sections of steel tubing (usually 5 feet long) with steel helical flights around the outside. Segments of auger are added as the borehole advances, and samples are retrieved through the inside of the auger without having to remove the auger from the borehole during sampling.

With this technique, samples will be obtained either with standard split spoon or California drive samplers, or with a continuous core augering technique. The continuous coring technique can obtain up to 5-foot-long cores in a 5-foot-long sample barrel; however, at the RFP sampling will be conducted in increments of 2 feet to enhance sample recovery unless otherwise specified in the FSP. Drive sampling will normally obtain a 12- to 18-inch-long sample depending on the length of the sampler. Visual logging of the alluvial and bedrock materials will be performed according to SOP 3.1, Logging of Alluvial and Bedrock Material. Sampling for chemical analysis is addressed in this SOP. All sampling equipment will be protected from the ground surface with clear plastic sheeting. All drilling and sampling activities will be conducted in accordance with the project Health and Safety Plan.

5.1 EQUIPMENT AND MATERIALS

The following equipment and materials are needed for hollow-stem auger drilling and soil sampling. Only the types of samplers required by the sampling specified in the Field Sampling Plan (FSP) will be required on a given project.

- Drill rig equipped for drilling and sampling with hollow-stem augers
- Continuous core augering equipment (including 2-1/2- to 3-inch inside diameter sample barrel suitable for 2-foot sample rods)
- Standard split spoon sampler (ASTM D 1586)

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- California spoon sampler
- Brass (or stainless steel) California liners (2-inch-diameter)
- 3-inch-long stainless steel volatile/semi-volatile organic analysis (VOA) sample liner for continuous auger core barrel
- Teflon® film (cut in 4-inch x 4-inch squares)
- Plastic caps for California and VOA liners
- Self-adhesive labels
- Ice chests (sample shuttles)
- High-pressure steamer/sprayer
- Long-handled bristle brushes
- Wash/rinse tubs
- Phosphate-free lab-grade detergent (e.g., Liquinox)
- Location map
- Weighted tape measure
- Water level probe

- Distilled water
- Drums for containment of cuttings
- Appropriate health and safety equipment
- Field book
- Boring log forms

5.2 DRILLING PROCEDURES

Boreholes will be drilled by using hollow-stem augers and the sampling equipment required by the FSP. All drilling equipment, including the rig, water tanks, augers, drill rods, samplers, etc., will be decontaminated before arrival at the work area site. Between boreholes, all down-hole equipment will be decontaminated, and sampling equipment will be decontaminated between samples. Equipment will be inspected for evidence of fuel oil or hydraulic system leaks (See SOP 1.3, General Equipment Decontamination, and SOP 1.4, Heavy Equipment Decontamination). If lubricants are required for down-hole equipment, only pure vegetable oil will be used.

Before drilling, borings will have been located, numbered, and identified using stakes or spray paint on paved surfaces. Buried metal objects will have been located by using geophysical methods, and utility clearance will have been accomplished according to SOP 3.10, Borehole Clearing.

After boreholes have been cleared and obstructions removed, an exclusion zone will be established according to the project Health and Safety Plan, and the drill rig will be set up. The boring will be advanced to the depth indicated and sampled according to the FSP.

For borings where environmental samples will be obtained in the bedrock, the borehole will be drilled into the top of the weathered bedrock prior to installation of a casing according to SOP 3.3, Isolating Bedrock From Alluvium With Grouted Surface Casing. The bottom of the surface casing will be embedded below the weathered bedrock surface in soil borings according to SOP 3.3. The embedment may vary for monitoring wells according to the FSP or SOPAs. After installing the casing, the bedrock will be drilled and sampled by using hollow-stem augers small enough to fit through the casing in boreholes designated for environmental sampling. In boreholes that are drilled only for geologic logging, hydraulic or geotechnical testing, or monitoring wells, the portion of the borehole below the casing may be drilled using conventional rotary or rock coring techniques (SOP 3.4, Rotary Drilling and Rock Coring). This will normally allow for the use of a smaller diameter surface casing.

It is anticipated that most or all of the weathered bedrock can be drilled and sampled by using the continuous hollow-stem auger coring method. However, if bedrock that is sufficiently cemented to render this method ineffective is encountered in borings designated for environmental sampling, the cemented zone will be rock cored using filtered air as the drilling medium according to SOP 3.4, Rotary Drilling and Rock Coring. After the cemented zone is penetrated, the boring will continue with hollow-stem auger coring. If necessary, this may require reaming the cored section with air-rotary techniques.

The borings will be logged lithologically by examination and classification of the samples. Documentation will be completed by the site geologist according to Section 8.0 of this SOP. SOP 3.1, Logging Alluvial and Bedrock Material, describes procedures for material classification and borehole logging.

At the first indication of free water on the sampler or in samples, the time and estimated depth will be recorded. However, it is frequently difficult to determine the true water level in hollow-stem auger borings at the time of drilling, particularly when drilling in low-permeability soil or bedrock.

Therefore, water levels will also be measured after drilling. In low-permeability deposits, it is possible for a borehole to be drilled below the groundwater level and not collect water for several hours or even days. It is therefore important to note moisture changes in the samples when evaluating groundwater conditions at the time of drilling. During the drilling and while the augers are being removed, the cuttings and unsaved portions of samples from the boring will be containerized according to SOP 1.8, Handling of Drilling Fluids and Cuttings, and SOP 1.9, Handling of Residual Samples.

5.3 SAMPLING PROCEDURES

5.3.1 Continuous Core Auger Sampling

The continuous coring method advances a split barrel that is contained within the lead auger. The augers rotate around the sampler and cut while the sample barrel is prevented from rotating. Continuous core samples are collected in the barrel. The barrel will be unlined except for a 3-inch long stainless steel VOA/semi-VOA sample liner placed at the bottom end of the barrel directly behind the cutting shoe. Once the core barrel has been removed from the borehole and opened, the VOA sample liner will immediately be capped with Teflon[®]-lined plastic caps, sealed with electrical tape, labeled, and placed in a cooler with ice. The remainder of the sample will then be classified, logged, peeled, composited (if called for in the FSP), and placed in appropriate containers for analytical testing according to SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples. Sample intervals and requirements for compositing are defined in the FSP or SOPA.

Sample peeling will involve discarding the portion of sample that was in direct contact with the sampler. Compositing the sample will involve placing the peeled sample in a stainless steel bowl and mixing with a stainless steel instrument. Soil particles (gravels) larger than the jar mouth will

be discarded. Peeling and compositing will be conducted with separate decontaminated stainless steel instruments.

Samples for geotechnical testing will consist of approximately 3/4-filled pint-sized glass jars with air-tight lids placed in compartmented shipping cartons designed to prevent breakage of the jars. Sample peeling is not required for geotechnical samples.

5.3.2 Drive Sampling

Drive samples will be obtained in general accordance with ASTM Designation D 1586. After drilling to the predetermined depth, the standard split spoon or California sampler will be attached to the end of the drill rod and lowered to the bottom of the boring. The standard 140-pound hammer assembly will then be attached to the top of the drill rod. The depth to the bottom of the sampler will be recorded, and reference marks at 6-inch increments will be placed on the drill rod. The test consists of driving the sampler with the standard 140-pound hammer dropped 30 inches.

When using the 2-inch-outside-diameter (O.D.) standard split spoon sampler, drive the sampler through three 6-inch increments (or 100 blows, whichever occurs first), with the sum of the last two increments being the Standard Penetration Count or Blow Count or N-value, and the first 6-inch increment being considered as seating.

A California barrel with brass (or stainless steel) liners may be substituted for the standard split barrel. The integrity of the sample can generally be better maintained since thin-walled liners containing the sample can be removed from the barrel and sealed. Since the California sampler is shorter than the standard split spoon sampler, it will be driven only 12 inches, with blow counts recorded for each 6-inch increment. However, several blows are required before marking and counting blows to seat the sampler.

A California barrel has a 2.5-inch O.D. and a 2-inch inside diameter (I.D.) Modified California samplers with larger diameters are also available. The liners for a conventional California barrel have a 1.94-inch I.D. Although not precisely equivalent, the blow count obtained by using a 2-inch I.D. California barrel is frequently considered to be comparable to the N-value obtained using a standard barrel. Blow counts using larger samplers will not be equivalent, and larger hammers may be required to drive them under some conditions.

A rope and cathead arrangement is generally used to obtain drive samples. Automatic trip hammers are sometimes used. If a rope and cathead arrangement is used, excessive turns of the rope on the cathead must be avoided, since they will result in friction and drag between the rope and cathead. Two turns of the rope on the cathead will be used and sufficient slack in the rope provided during hammer freefall to prevent excessive friction.

Standard split spoon samples saved for geotechnical testing will consist of 3/4-filled pint-sized glass jars with airtight lids placed in compartmented shipping cartons designed to prevent breakage of the jars. Samples for analytical testing will be peeled (see Subsection 5.3.1) and placed in containers described in SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples. For California liner samples, the geotechnical samples may be saved in the liners with plastic end caps.

5.4 BORING COMPLETION AND ABANDONMENT

After the borehole has been advanced to its final depth, it will either be abandoned or completed as a monitoring well (see SOP 3.5, Plugging and Abandonment of Boreholes, and SOP 3.6, Monitoring Well and Piezometer Installation).

The boring location stake will be left in the ground adjacent to the borehole, and a board or other cover placed over the hole until it has been grouted. All boreholes to be abandoned with a depth

greater than 1 foot will be grouted the same day that abandonment is completed. The boring location stake will then be placed in the grout.

6.0 QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

Quality Assurance (QA) and Quality Control (QC) activities will be accomplished according to applicable project plans as well as quality requirements presented in this SOP.

QA samples for soils fall into five categories:

- Duplicate
- Matrix spike
- Matrix spike duplicate
- Equipment rinsate
- Field blank

SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples describes the general handling of samples. Applicable project plans specify QA sample frequencies.

Sample collection procedures will be the same as those described in Section 5.0 for duplicate, matrix spike, and duplicate matrix spike samples. These samples are intended to be as close to exact replicates of the original samples as possible. They are obtained immediately adjacent to the planned samples that they are intended to duplicate.

A rinsate sample from sampling equipment is intended to check for potential contamination of the sample by the sampling equipment. For the soil sampling operation, a rinsate sample will be collected from sampling equipment with any liners in place before the sampling equipment is used. Approximately 3 liters of distilled water will be rinsed over a decontaminated sampler and collected

in a large decontaminated stainless steel bowl. A decontaminated glass beaker will be used to dip the water from the bowl and fill the sample bottles. The rinsate samples will be analyzed for the same parameters as the soil samples.

Field blank samples are containers filled with clean water that are handled and transported the same as the other samples to check for potential cross-contamination resulting from field handling and transportation procedures.

7.0 DECONTAMINATION

Generalized equipment decontamination procedures will include:

- Sampling equipment. Decontamination will be conducted between individual sampling points to minimize potential cross-contamination. Sampling equipment will be decontaminated according to SOP 1.3, General Equipment Decontamination. During drilling and sampling, decontaminated equipment will be placed on new plastic or racks until it is used. At least two sets of samplers will be available so that one set can be used while the other is being decontaminated.
- Drilling equipment. Decontamination of augers, drill stems, drill bits, and other down-hole equipment will be conducted after each boring is complete. Drill rigs will be decontaminated when moved out of a work area or when they become unusually dirty as a result of site or drilling conditions, at the discretion of the site or project manager. Decontamination of drilling equipment is described in more detail in SOP 1.4, Heavy Equipment Decontamination.

8.0 DOCUMENTATION

All information required by this SOP will be documented on the Borehole Log Form (in SOP 3.1, Logging Alluvial and Bedrock Materials) and the Hollow-Stem Auger Drilling Field Activities Report Form, Form 3.2A. The Field Activities Report Form will be filled out for each day of drilling at a given borehole location and, in situations where more than one boring is drilled and completed per day per drill rig, at least one form will be completed per boring. The borehole log will include information on subsurface material classification and lithology. The Field Activities Report will include the following information and have space for comments and documentation of general observations:

- Project, crew, drilling contractor and borehole identifications
- Date
- Weather
- Equipment descriptions (rig, bits, etc.)
- Water level
- Depth to bedrock
- Borehole depth and diameter
- Decontamination
- Waste types, volumes and drums used
- End-of-day status (i.e., partially complete, abandonment, etc.)
- Chronological record of activities

**HOLLOW STEM AUGER DRILLING
FIELD ACTIVITIES REPORT**

PROJECT NUMBER	DATE
PROJECT NAME	
BOREHOLE IDENTIFICATION	
WEATHER CONDITIONS	
RIG TYPE	
DRILLING COMPANY/DRILLER	
GEOLOGIST/ENGINEER	
CREW MEMBERS	
WATER LEVEL/TIME	
TOTAL DEPTH	
DECONTAMINATION	
WASTE TYPES, VOLUMES AND DRUMS USED	
DIAMETER OF BORING	
TYPE AND SIZE OF AUGERS AND BIT	
SAMPLING TYPES, DEPTHS	
HAMMER SIZE	
DEPTH TO BEDROCK	
END-OF-DAY STATUS	
CHRONOLOGICAL RECORD OF ACTIVITIES	
COMMENTS	

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TITLE:
ISOLATING BEDROCK FROM THE
ALLUVIUM WITH GROUTED
SURFACE CASING

Approved By:

J. W. Langford

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FIGURE 3.3-1 SCHEMATIC DESIGN OF GROUTED SURFACE CASING

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to install surface casing grouted into the top of bedrock to isolate the bedrock from the alluvium. The intent of implementing this SOP is to prevent cross-contamination from the alluvium into the bedrock. This will be required for environmental sampling of the bedrock in boreholes and for construction of bedrock monitoring wells. The following items are discussed in this SOP:

- Drilling methods for advancing borehole
- Surface casing installation materials
- Surface casing installation procedures

This SOP describes the field procedures that will be used to install surface casing and document the procedures in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the installation of grouted surface casing will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervisor of another qualified person.

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4.0 REFERENCES

4.1 SOURCE REFERENCES

This is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1. September, 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP 1.3, General Equipment Decontamination
- SOP 1.4, Heavy Equipment Decontamination
- SOP 3.1, Logging Alluvial and Bedrock Material
- SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP 3.4, Rotary Drilling and Rock Coring
- SOP 3.10, Borehole Clearing

5.0 PROCEDURES FOR INSTALLING SURFACE CASING

Surface casings will be installed in boreholes drilled and logged according to SOP 3.2, Drilling and Sampling Using Hollow-stem Auger Techniques, and SOP 3.1, Logging Alluvial and Bedrock Material. All drilling and sampling equipment will be decontaminated according to SOP 1.3, General Equipment Decontamination, and protected from the ground surface with clear plastic sheeting or placed on clean drill racks.

5.1 EQUIPMENT AND MATERIALS

The following is a list of equipment and materials used for surface casing installation:

- Drill rig with appropriate-size augers
- Surface casing
- American Colloid Pure Gold Bentonite grout (or approved equivalent)
- Rubber grout-displacement plug (1/2-inch diameter larger than inside diameter of casing)
- Tremie pipe and grout pump
- High pressure steamer sprayer
- Mechanical grout mixer
- Weighted tape measure

- Water level probe
- Pipe cutter
- Appropriate documentation forms
- Drums for containment of cuttings
- Appropriate health and safety equipment
- Pre-approved water from a potable source (see SOP 1.3, General Equipment Decontamination)
- Plastic Sheeting

5.1.1 Casing Requirements

Surface casing will consist of new schedule 40 PVC or steel well casing. PVC casing will be used for nominal casing diameters of 6 inches or less. Larger casings will be steel. Joints will be water-tight threaded couplings made without welds, solvents or lubricants. The casing will be embedded into the top of bedrock and extend to approximately 1 foot above the ground surface. Casing centralizers will be attached to the casing to allow uniform grouting. At least 2 centralizers will be required, one within 5 feet of the bottom and the other within 5 feet of the top of the casing. All surface casing will be free of foreign material and will be decontaminated according to SOP 1.3, General Equipment Decontamination. Decontaminated casing will be stored in plastic sheeting or kept on clean racks prior to use.

5.1.2 Grout Requirements

The grout mixture will consist of reduced pH bentonite grout (American Colloid Pure Gold or approved equivalent) mixed in a powered mechanical grout mixer according to the grout manufacturer's recommendations. The grout will contain at least 30 percent solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. The density will be measured using a mud balance.

5.2 DRILLING METHODS

Boreholes will be drilled into the top of bedrock using hollow-stem augers. Alternatively, conventional rotary or reverse-circulation rotary methods may be used; however, due to the variability of these methods, an SOP addendum (SOPA) may be required. Drilling equipment including the rig, augers, drill rods, and samplers will be decontaminated according to SOP 1.4, Heavy Equipment Decontamination, and SOP 1.3, General Equipment Decontamination. The borehole will be of sufficient diameter to allow a 2-inch thickness of bentonite grout to be placed outside of the casing. Each borehole location will be cleared according to SOP 3.10, Borehole Clearing, before drilling.

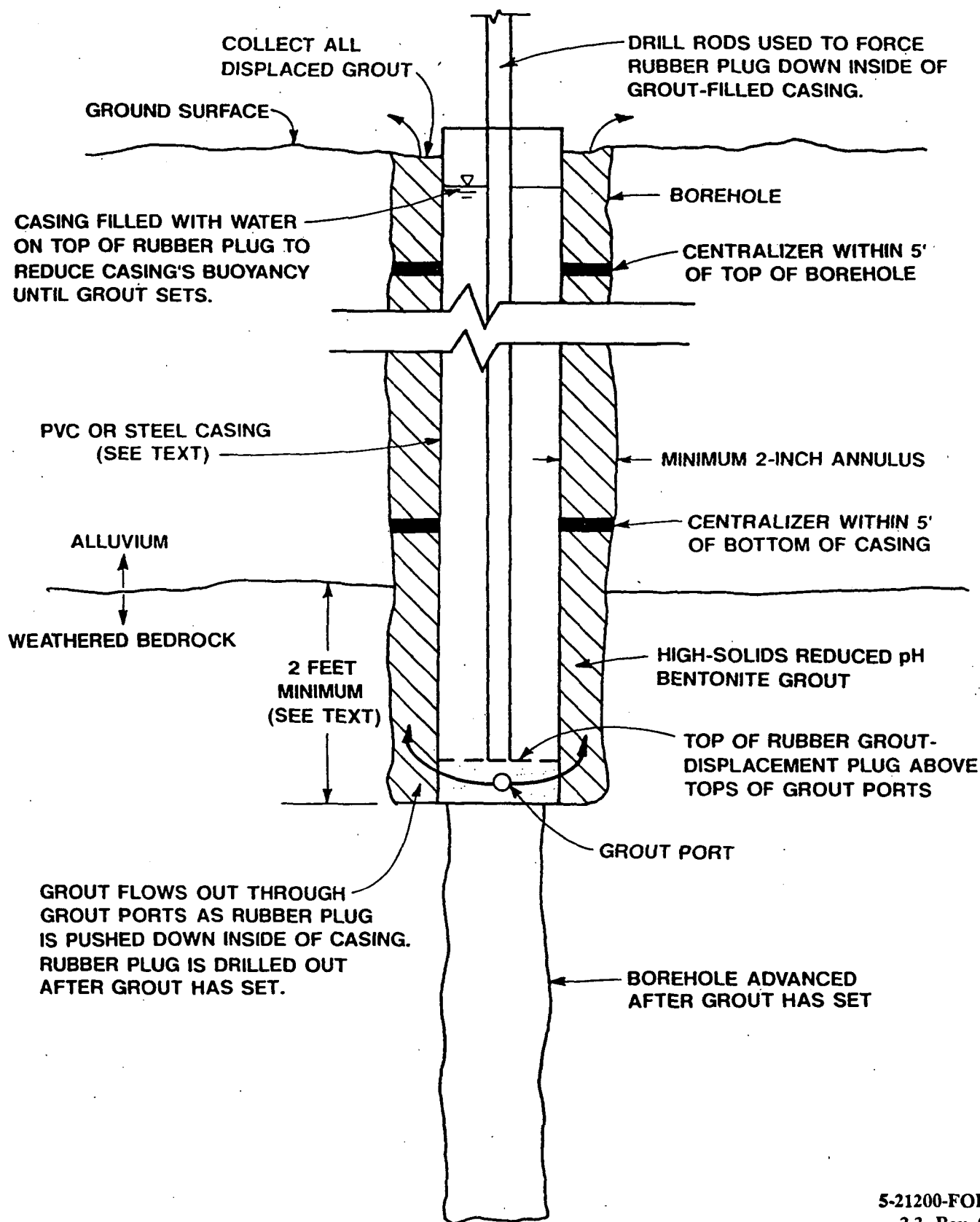
The embedment of casing into the bedrock will be a minimum of 2 feet into the weathered bedrock. However, the intent is to place the bottom of the casing approximately 2 feet below the interface describing a substantial reduction in hydraulic conductivity. If the uppermost weathered bedrock is highly weathered and/or fractured, this embedment depth will be adjusted downward. A conservative approach will be used early in the program with casing embedment on the order of 5 feet. The project hydrogeologist responsible for the on-going hydrogeologic site characterization will be responsible for establishing and documenting protocols for surface casing embedment based on the observed degree of weathering and fracturing after the first several boreholes are completed and evaluated.

5.3 SURFACE CASING INSTALLATION AND SEALING PROCEDURES

Surface casing will be installed by placing the casing into the grout-filled borehole and then forcing the grout from within the casing into the annular space by pushing a rubber plug down the casing thus displacing the grout out through grout ports at the bottom of the casing. Implementing this SOP is intended to provide a uniform seal from the base of casing to the ground surface. Figure 3.3-1 depicts the casing installation described below.

Surface casing installation will begin after the borehole has been drilled into the top of bedrock the required depth specified in the Field Sampling Plan according to the following steps:

- (1) Measure the borehole total depth using a weighted tape measure. The weight on the measure tape will be stainless steel in the event that it accidentally becomes embedded.
- (2) Pump the grout mixture into the inside of the augers to the bottom of the hole using a tremie pipe, until undiluted grout flows out of the top of the augers. As the augers are removed, add grout into the augers to keep the level at the top of the augers until all of the augers have been removed and the borehole is completely full of grout. (Alternatively, if subsurface conditions allow the borehole to remain open, the borehole may be tremie-grouted after the entire string of augers is removed. If this is attempted and the borehole caves, it will be redrilled and tremie-grouted using the augers as described above).
- (3) Drill three equally spaced 1-inch diameter holes (grout ports) into the wall of the casing immediately above the bottom of the casing. The distance between the bottom of the casing and the holes will not exceed the length of the rubber plug.
- (4) Lower the surface casing into the borehole. Install the required centralizers at 5 feet below surface and 5 feet above the bottom of the casing while running the casing in the borehole.



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Figure 3.3-1 - Schematic Diagram of Grouted Surface Casing

- (5) Once the casing is at the bottom of the borehole, place a rubber plug, intended for displacing grout from within the casing (1/2-inch diameter larger than the inside of the casing), inside the casing and force it down to the bottom of the casing by drill rods using hydraulic feed from the rig. Add RFP potable water to the inside of the casing as the plug is being forced down. The water will aid in equalizing the pressure of the grout on the rubber plug until the grout has set.
- (6) Place a protective cover over the top of the casing until the grout has set for at least 24 hours.
- (7) Remove the water inside the casing by air-lift methods or bailing before the plug is drilled out and the borehole is advanced past the bottom of the casing.

6.0 DOCUMENTATION

All information required by this SOP will be documented on the Borehole Log Form found in SOP 3.1, Logging Alluvial and Bedrock Materials, and on the Surface Casing Installation Field Activities Report Form, Form 3.3A. Form 3.3A will be filled out for each day of drilling at a given borehole location; and, in situations where more than one boring is drilled and completed per day per drill rig, at least one form will be completed per boring. The borehole log will include information on subsurface material classification and lithology. The Field Activities Report will include the following information and have space for comments and documentation of general observations:

- Date, Start and Completion
- Project, conditions and borehole identifications
- Weather

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- Equipment descriptions (rig, etc.)
- Personnel
- Depth to top of weathered bedrock
- Bottom casing depth
- Borehole diameter
- Casing diameter
- Type of casing (schedule, wall-thickness, grade, etc.)
- Centralizer depths
- Centralizer type
- Casing stick-up (measured height above ground level)
- Quantity and composition of grout (including grout/water mix ratio, weight/pound)
- Joint/coupling description
- Comments

**SURFACE CASING INSTALLATION
FIELD ACTIVITIES REPORT**

PROJECT NUMBER	_____	DATE	_____
PROJECT NAME	_____		
BOREHOLE IDENTIFICATION	_____		
COORDINATES	_____	North	_____ East _____
WEATHER CONDITIONS	_____		
RIG TYPE	_____		
DRILLING COMPANY/DRILLER	_____		
GEOLOGIST/ENGINEER	_____		
CREW MEMBERS	_____		
WATER LEVEL/TIME	_____		
TOTAL DEPTH	_____		
WASTE TYPES, VOLUMES AND DRUMS USED	_____ _____ _____		
DIAMETER OF BORING CASING	Diameter _____	Type _____	
	Wall Thickness _____	Schedule _____	
CASING TOP/BOTTOM	Stickup _____	Below Grd. _____	
CENTRALIZERS TYPE LOCATIONS	_____ _____ _____		
GROUT COMPOSITION QUANTITY WEIGHT PER GALLON	_____ _____ _____ _____ _____		
DEPTH TO BEDROCK	_____		
END-OF-DAY STATUS	_____		
CHRONOLOGICAL RECORD OF ACTIVITIES	_____ _____ _____ _____ _____ _____		
COMMENTS	_____ _____ _____ _____ _____		

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TITLE:
ROTARY DRILLING AND ROCK
CORING

Approved:

J. W. Langman Jr.

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for rotary drilling and rock coring, using air and water as drilling media. It addresses equipment, field procedures, decontamination, and documentation, that will be used for rotary drilling and rock coring, and describes documentation of these procedures in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the plugging and abandonment at boreholes will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Ground-Water Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1. Washington D.C. September, 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced in this SOP are as follows:

- SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP 1.4, Heavy Equipment Decontamination
- SOP 3.10, Borehole Clearing
- SOP 1.3, General Equipment Decontamination
- SOP 1.8, Handling of Drilling Fluids and Cuttings
- SOP 3.1, Logging Alluvial and Bedrock Material
- SOP 3.6, Monitoring Well and Piezometer Installation
- SOP 3.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP 3.5, Plugging and Abandonment of Boreholes

5.0 EQUIPMENT AND PROCEDURES

5.1 GENERAL

Rotary drilling and coring methods that use air or water as the drilling media are common techniques employed to obtain stratigraphic, lithologic, hydrogeologic, geotechnical, and environmental data, as well as a means for monitoring well installation. In general, hollow-stem continuous-flight augers will be the preferred technique for drilling boreholes to collect environmental samples of soil and rock (see SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques). The use of air or water can alter analytical chemistry or physical property test results by altering sample moisture, or by volatilizing contaminants (in case of air) or by washing

them away (in the case of water). Using water when drilling can also alter the groundwater chemistry in the vicinity of the borehole, and needs to be accounted for during development of wells. Rotary drilling and rock coring may be used for advancing boreholes with or without environmental sampling in zones of hard material which cannot be penetrated with augers.

Samples obtained for analytical chemistry testing will be prepared and contained in general accordance with SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques. In general, air will be the drilling medium used when it is necessary to penetrate cemented zones of rock in auger borings drilled for environmental sampling. Water will typically be used as the drilling medium when drilling relatively deep bedrock wells and when obtaining rock core exclusively for geologic logging. Alternatively, dual-tube air percussion or ODEX drilling methods using water or air may be appropriate for some conditions. The appropriate work plan or a standard operating procedure addendum (SOPA) will outline drilling requirements for each project.

5.2 EQUIPMENT AND MATERIALS

5.2.1 General Rotary Drilling Equipment

The following is a list of equipment and materials for rotary drilling:

- Drill rig with appropriately sized drill bits and rods
- Portable recirculation tanks for water rotary
- Preapproved water for water rotary
- Conveyance equipment (pumps and hoses)
- Air compressor with appropriate air filter(s)
- High pressure steamer/sprayer
- Wash/rinse tubs
- Weighted tape measure

- Phosphate-free, lab grade detergent (e.g., Liquinox)
- Water level probe
- Appropriate health and safety equipment
- Drums for containment of cuttings and fluids (SOP 1.8, Handling of Drilling Fluids and Cuttings)
- Boring log form
- Field activities report form
- Pint-sized plastic bottles with screw caps for cuttings (SOP 3.1, Logging Alluvial and Bedrock Material)

5.2.2 Supplemental Equipment for Rock Coring

Additional equipment for rock coring will consist of the following:

- Core barrel assembly
- Wire line or core rods
- Coring log forms
- Core boxes with wooden blocks
- Measuring tape
- Camera (photography is security controlled at Rocky Flats Plant)
- Core barrel rack
- Plastic wrap for core
- Marking pen, black, permanent

5.3 PROCEDURES

Boreholes will be drilled using a rig equipped with rotary drilling equipment capable of advancing the borehole to the depth specified in the Field Sampling Plan (FSP). All drilling equipment,

including the rig, water transportation tanks, bits, and drill rods, will be decontaminated according to SOP 1.4, Heavy Equipment Decontamination and SOP 1.3, General Equipment Decontamination. These decontamination procedures will also be followed between boreholes. Drilling equipment will be inspected to ensure that hydraulic system and fuel leaks do not introduce organic contamination on site or into the borehole. Any leaks that may introduce such contamination will be repaired before drilling. Only pure vegetable oil products may be used to lubricate downhole drilling and sampling equipment.

Borehole locations will be cleared before drilling, according to SOP 3.10, Borehole Clearing. Drill cuttings and fluids will be handled according to SOP 1.8, Handling of Drilling Fluids and Cuttings. Boreholes will be abandoned according to SOP 3.5, Plugging and Abandonment of Boreholes. All procedures will be conducted according to the applicable Health and Safety Plan. Project-specific requirements will be addressed in a SSOPA.

5.3.1 Rotary Drilling Techniques

Conventional rotary drilling involves the introduction of a drilling medium (fluid) into the borehole through the drill rods and circulation of the medium back up the hole to remove drill cuttings. The hole is advanced by the cutting action of a rotating drill bit at the bottom of the hole. Reverse circulation methods are similar to conventional rotary methods, except that the drilling medium is injected down the annulus between an inner and outer double casing and returns back up the inside of the inner casing. Some reverse circulation methods use rotary techniques, some use non-rotating percussion techniques, and some use a combination of the two. Samples of cuttings obtained when rotary drilling to be saved for geotechnical testing or future geologic reference will be placed in pint-sized plastic jars with screw-on tops and saved in core boxes.

5.3.1.1 Water

Water used for rotary drilling will consist of RFP potable water. Water transportation tanks and conveyance equipment will be contaminant-free and dedicated for the use with preapproved water to ensure that the preapproved water introduced into the borehole is also contaminant-free. Portable decontaminated water recirculation tanks will be used for rotary operations. Excavated sumps or pits (lined or unlined) will not be used. Decontamination of tanks and conveyance equipment will also be conducted in accordance with SOP 1.3, General Equipment Decontamination and/or SOP 1.4, Heavy Equipment Decontamination.

5.3.1.2 Air

Conventional air compressors used for air rotary methods contain oil for lubricating moving parts and compress air and oil in their operation. To avoid introducing contaminants into the borehole, a filtration system designed to provide oil-free air and approved by EG&G will be used. Depending on the requirements of the particular project, such a system may consist of an air-cooled aftercooler, a regenerative dryer, a coalescing filter, and a particulate afterfilter, all arranged in series. The particular filtration system design will depend on the compressor equipment, the project requirements, and anticipated ambient conditions. The filtration system will be matched appropriately to the compressor's capacity so that the reduction in the flow of air to the drilling equipment is tolerable. The filtration system components will be changed or monitored according to the requirements of the design during operation and a record of this kept on the field activities report form (see Section 7, Documentation).

Dust control measures may also be required according to the Field Operations Plan (FOP) and Health and Safety Plan (HSP). The airborne dispersion of cuttings can be controlled to some extent by circulating the return air through a vortex or cyclone.

5.3.2 Rock Coring

Continuous core samples collected using rock coring methods can be used to obtain relatively undisturbed samples of rock for stratigraphic, lithologic, hydrogeologic, and environmental data. Conventional rock coring methods use a diamond coring bit instead of a conventional tricone or granular rotary bit.

Continuous core samples will be extracted from the core barrel, placed on core racks, and logged by a geologist according to SOP 3.1, Logging Alluvial and Bedrock Material. Rock core to be saved for geotechnical testing or further geologic observations will be placed in plastic core wrap and then placed in core boxes with appropriately sized dividers to protect and preserve the orientation of the core during transportation and storage. Coring equipment will also be decontaminated according to SOP 1.3, General Equipment Decontamination.

Air or water drilling media used for coring must be contaminant-free. Therefore, the provisions required in Subsections 5.3.1.1 and 5.3.1.2 for drilling fluids also apply to rock coring procedures.

6.0 DECONTAMINATION

Generalized equipment decontamination procedures will include:

- Sampling equipment. Decontamination will be conducted between individual sampling points to minimize potential cross-contamination. Sampling equipment will be decontaminated according to SOP 1.3, General Equipment Decontamination. During drilling and sampling, decontaminated equipment will be placed on new plastic sheeting or racks until it is used. At least two sets of samplers will be available so that one set can be used while the other is being decontaminated.

- Drilling equipment. Decontamination (augers, drill stems, drill bits, and other downhole equipment) will be conducted after each boring is complete. The drill rig will be decontaminated when moved to a new borehole/well site. Decontamination of drilling equipment is described in SOP 1.4, Heavy Equipment Decontamination.

7.0 DOCUMENTATION

All information required by this SOP will be documented on the Borehole Log Form (in SOP 3.1 Logging Alluvial and Bedrock Materials) and the Rotary/Core Drilling Field Activities Report Form, Form 3.4A. The Field Activities Report Form will be filled out for each day of drilling at a given borehole location and, in situations where more than one boring is drilled and completed per day per drill rig, at least one form will be completed per boring. The borehole log will include information on subsurface material classification and lithology. The Field Activities Report will include the following information and have space for comments and documentation of general observations:

- Project, and borehole identifications
- Weather
- Equipment conditions descriptions (rig, bits, etc.)
- Personnel
- Drilling fluid used
- Drilling fluid return/loss and pressures
- Sampling information
- Waste disposal information
- Water level
- Borehole information
- Compressor/pump type

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- End-of-day status (i.e., partially complete, abandoned, etc.)
- Chronological record of activities

**ROTARY/CORE DRILLING
FIELD ACTIVITIES REPORT**

PROJECT NUMBER	_____	DATE	_____
PROJECT NAME	_____		
BOREHOLE IDENTIFICATION	_____		
COORDINATES	_____	North	_____ East _____
WEATHER CONDITIONS	_____		
RIG TYPE	_____		
DRILLING COMPANY/DRILLER	_____		
GEOLOGIST/ENGINEER	_____		
CREW MEMBERS	_____		
WATER LEVEL/TIME	_____		
TOTAL DEPTH	_____		
WASTE TYPES, VOLUMES AND DRUMS USED	_____ _____ _____ _____		
DIAMETER OF BORING	_____		
TYPE AND SIZE OF BIT	_____		
SAMPLING TYPES AND DEPTHS	_____ _____ _____ _____		
SIZE AND TYPE OF CASING	_____		
CASING HAMMER SIZE	_____		
DRILLING FLUID TYPE	_____		
FLUID RETURN/LOSS AND PRESSURES	_____ _____ _____ _____		
COMPRESSOR/PUMP TYPE	_____		
DEPTH TO BEDROCK	_____		
END-OF-DAY STATUS	_____		
CHRONOLOGICAL RECORD OF ACTIVITIES	_____ _____ _____ _____ _____		
COMMENTS	_____ _____ _____ _____ _____		

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TITLE:
PLUGGING AND ABANDONMENT
OF BOREHOLES

Approved By:

J. W. Langman

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to plug and abandon (P&A) boreholes. Plugging refers to the physical process of filling the hole with grout while abandonment refers to the completion and documentation of all of the requirements of this SOP.

A borehole is defined for the purpose of this SOP as a ground penetration that is drilled for the primary purpose of obtaining geologic and environmental information. Generally, a borehole will provide retrieval of cores, cuttings, and geophysical data. Boreholes may be uncased or partially or fully cased. This SOP addresses abandonment of boreholes immediately after completion of drilling; therefore, the depth, diameter, and other features of the borehole will be known. Unless the status of a borehole is changed, it will be plugged and abandoned immediately after the desired data are collected.

The status of a borehole may be changed to that of a well. A well is defined for the purpose of this SOP as a surface penetration drilled for the purpose of installing a water well; i.e., for monitoring and/or production, or a cased penetration designed to obtain piezometric information. Abandonment of wells is addressed in SOP 3.11, Plugging and Abandonment of Wells. Abandonment of previous ground penetrations of unknown status is also addressed in SOP. 3.11.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the plugging and abandonment at boreholes will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under supervision of another qualified person.

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4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA. OSWER-9950.1. Washington D.C. September 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are:

- SOP 1.5, Handling of Purge and Development Water
- SOP 1.8, Handling of Drilling Fluids and Cuttings
- SOP 1.9, Handling of Residual Samples
- SOP 1.3, General Equipment Decontamination
- SOP 1.4, Heavy Equipment Decontamination
- SOP 3.10, Borehole Clearing
- SOP 3.11, Plugging and Abandonment of Wells
- SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques

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- SOP 3.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP 3.4, Rotary Drilling and Rock Coring

5.0 EQUIPMENT AND PROCEDURES

5.1 MATERIALS AND EQUIPMENT

The following materials and equipment may be used:

- Health and safety monitoring equipment and personal protective equipment according to the Health and Safety Plan
- Borehole plugging and abandonment form
- Black waterproof ink pen
- Drill rig and associated equipment
- Reduced pH bentonite grout (American Colloid Pure Gold, or approved equivalent), mixed in a powered mechanical grout mixer according to manufacturer's recommendations. The grout will contain at least 30 percent solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. A mud balance will be used to check grout density prior to pumping for each borehole.
- Cement bentonite grout (proportioned as 1 sack [94 pounds] of Portland cement, 5 pounds of powdered bentonite, and approximately 8 gallons of potable water)

- Portable metal tanks for flushing and mixing
- High pressure steamer/spray
- Phosphate-free, lab grade detergent (e.g., Liquinox)
- Drums for containment of borehole effluent and sediment
- Weighted measuring tape
- Mirror
- Spotlight

5.2 PROCEDURES

Equipment for plugging and abandoning boreholes will be used according to the requirements of SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques and SOP 3.4, Rotary Drilling and Rock Coring. These requirements include use of contaminant-free lubricants only (i.e., pure vegetable oil) and visual monitoring of equipment for hydraulic and/or fuel or oil leaks. All procedures will be conducted according to the applicable Health and Safety Plan. If necessary, project-specific requirements will be addressed in a Standard Operating Procedures Addendum (SOPA).

Plugging will involve placing bentonite grout by a tremie pipe positioned at the bottom of the hole. The grout will be mixed in a powered mechanical grout mixer. The tremie pipe can be raised during grouting, but it will be maintained from at least 5 to 10 feet below the upper level of the grout. The grout will be pumped until any other fluids have been displaced from the hole and

undiluted grout is observed flowing from the hole. The tremie pipe will then be removed from the hole. After settlement of the bentonite grout, the hole will be cleaned out to a depth of approximately 3 feet and a cement bentonite grout will be placed from the ground surface to a depth of approximately 3 feet. This cement bentonite grout cap will be installed after 24 hours or more to allow for primary grout settlement. If the initial grout settlement is 3 feet or more, the upper grout surface will be rehydrated by adding water and waiting approximately 30 minutes prior to placing the cement bentonite grout cap. Alternatively, the dehydrated grout may be removed. A metal cap with borehole ID and survey information will be embedded in the cement bentonite grout. The following information will be inscribed in the cap (see Field Sampling Plan (FSP) for survey requirements).

- Borehole number
- Survey coordinates
- Elevation
- Date

A grouted surface casing will have been placed in many boreholes prior to completion of drilling (see SOP 3.3, Isolating Bedrock from the Alluvium with Surface Casing). These casings will be unscreened PVC or steel casing for the purpose of isolating the bedrock from possible cross-contamination by the alluvium during drilling. Steel casing will be removed during borehole abandonment. PVC casing may be left in place except for the upper 3 feet where cement grout will be placed. Steel casing will be decontaminated after removal. Abandonment procedures must not allow cross-contamination from the alluvium into the bedrock or surface soils. This will require grouting the portion of borehole in bedrock prior to casing removal. If difficulties are encountered removing casing, further measures, such as overdrilling, may be required according to SOP 3.11, Plugging and Abandonment of Wells.

All fluids displaced from the borehole during grouting will be collected and handled according to SOP 1.5, Handling of Purge and Development Water, and SOP 1.8, Handling of Drilling Fluids and Cuttings. This will require provision at the ground surface to collect fluid, such as surface casing discharging to a tank. In very deep boreholes when large quantities of fluids are anticipated, more elaborate measures such as grading the area and constructing lined pits, may be required to control displaced wastes. This will be addressed in an SOPA.

Upon completion of plugging, the rig and associated equipment will be decontaminated according to SOP 1.3, General Equipment Decontamination and SOP 1.4, Heavy Equipment Decontamination. Remaining waste materials will be handled according to SOP 1.8, Handling of Drilling Fluids and Cuttings. The ground surface at the site will be restored to near original lines and grades. Landscaping and/or pavement will be replaced.

6.0 DOCUMENTATION

Information required by this SOP will be documented on the Borehole Log Form (in SOP 3.1 Logging Alluvial and Bedrock Materials) and the Borehole Abandonment Field Activities Report Form, Form 3.5A. The Field Activities Report form will be filled out for each day of abandonment activities at a given borehole location and, in situations where more than one boring is abandoned per day per drill rig, at least one form will be completed per boring. The boring log will include information on subsurface material classification, stratigraphy, and lithology. Waste handling will be documented according to SOP 1.8, Handling of Drilling Fluids and Cuttings. The Field Activities Report will include the following information and have space for comments and documentation of general observations:

- Project, crew, and borehole identifications
- Weather conditions
- Equipment descriptions (rig, tremie, pump, etc.)

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- Water level in borehole prior to abandonment (if any)
- Borehole depth/diameter
- Volume of grout placed
- Type/length/diameter of casing removed
- Type/depth/diameter of casing left in place
- End-of-day status (i.e., partially complete, cap set, etc.)
- Chronological record of activities

**BOREHOLE ABANDONMENT
FIELD ACTIVITIES REPORT**

PROJECT NUMBER	_____	DATE	_____
PROJECT NAME	_____		
BOREHOLE IDENTIFICATION	_____		
COORDINATES	_____ North	_____ East	_____
WEATHER CONDITIONS	_____		
RIG TYPE	_____		
DRILLING COMPANY/DRILLER	_____		
GEOLOGIST/ENGINEER	_____		
CREW MEMBERS	_____		
WATER LEVEL/TIME	_____		
TOTAL DEPTH/DIAMETER	_____		
WASTE TYPES, VOLUMES AND DRUMS USED	_____		

TREMIE AND PUMPING EQUIPMENT	_____		

GROUT VOLUME PLACED TYPE/LENGTH/DIAMETER OF	_____		

CASING REMOVED	_____		

TYPE/LENGTH/DIAMETER OF CASING LEFT IN PLACE	_____		

END-OF-DAY STATUS	_____		

CHRONOLOGICAL RECORD OF ACTIVITIES	_____		

COMMENTS	_____		

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**TITLE:
MONITORING WELLS AND
PIEZOMETER INSTALLATION**

Approved By:

J.W. Langmuir

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for installing monitoring wells and open-pipe piezometers. This SOP describes the equipment for drilling, field procedures, well material specifications, and decontamination procedures that will be used to install and document monitoring wells in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the installation of monitoring wells and piezometers will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004 October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1, Washington D.C., September, 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced in this SOP are as follows:

- SOP 1.15, Use of PIDs and FIDs
- SOP 1.16, Field Radiological Measurements
- SOP 1.3, General Equipment Decontamination
- SOP 1.4, Heavy Equipment Decontamination
- SOP 3.1, Logging Alluvial and Bedrock Material
- SOP 3.2, Drilling and Sampling Using Hollow-stem Auger Techniques
- SOP 3.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP 3.4, Rotary Drilling and Rock Coring
- SOP 1.8, Handling of Drilling Fluids and Cuttings

5.0 EQUIPMENT AND PROCEDURES FOR MONITORING WELL AND PIEZOMETER INSTALLATION

Groundwater monitoring wells and open-pipe piezometers (observation wells) will be constructed in boreholes drilled and logged according to SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques, or SOP 3.4, Rotary Drilling and Rock Coring, and SOP 3.1, Logging Alluvial and Bedrock Material. The construction of monitoring wells is the same as that used for piezometers. The distinction between wells and piezometers is based on the intended use. Wells are used for obtaining samples of groundwater while

piezometers are intended only for water level measurements. If different types of piezometers are required (e.g., isolated electronic or pneumatic piezometers), they will be addressed in another SOP or in a standard operating procedure addendum (SOPA). All drilling and sampling equipment and materials will be protected from the ground surface with clear plastic sheeting or will be placed on clean drill racks.

Personnel installing monitoring wells need to be cognizant of the many factors influencing the screened intervals selected for wells. For example, water table wells should have screens of sufficient length at the appropriate depth to monitor the water table. Wells with slow recharge should have sufficient screen area to allow adequate sample volume. However, long screened intervals should generally be avoided since they are of limited value for characterizing discrete zones of contamination.

Selection of well screen intervals may also depend on the suspected presence of light or dense immiscible layers of contaminants floating on the water table or residing at the bottom of a hydrostratigraphic unit (HSU). Screened intervals across different HSUs should generally be avoided particularly where there is a potential for cross-contamination between HSUs to occur.

These factors must be addressed during project planning and the Field Sampling Plan (FSP) will normally provide rationale for the planned sampling. Personnel installing monitoring wells should be familiar with the FSP and the rationale used in determining well screen intervals.

5.1 EQUIPMENT AND MATERIALS

The following is a list of equipment and well materials for well installation:

- Drill rig with appropriately sized drill bit augers, and/or rods
- High pressure steamer/sprayer
- Sand bailer
- Long-handled bristle brushes
- Wash/rinse tubs
- Phosphate-free, lab grade detergent (e.g., Liquinox)
- Weighted tape measure
- Water level probe
- Distilled water
- Drums for containment of cuttings
- Appropriate health and safety equipment
- Field book
- Location map
- Boring log form
- Groundwater observation well report

5.2 DRILLING PROCEDURES

Boreholes for wells will be drilled by using a drill rig and drilling method capable of completing the well to the depth specified in the FSP. All drilling equipment, including the drill rig, water tanks, and all down-hole equipment will be decontaminated according to SOP 1.3, General Equipment Decontamination and SOP 1.4, Heavy Equipment Decontamination. The same decontamination procedure will also be followed between boreholes.

Before drilling, test borings/wells will have been numbered, located, and identified by using stakes, or nails with flagging, on paved surfaces. Drilling locations will be cleared for buried metal objects and utility interference according to SOP 3.10, Borehole Clearing.

Boreholes will be advanced from the ground surface to a predetermined target depth given in the FSP. Boreholes drilled for wells will be logged stratigraphically by examination of the sample cuttings or core samples according to SOP 3.1, Logging Alluvial and Bedrock Material.

If hollow-stem augers are used for alluvial wells, the boreholes will be augured as little as possible into claystone bedrock (approximately 6 inches or less), since the claystone bedrock cuttings may tend to be smeared along the side of the borehole in the alluvium. Therefore, after the augers have been advanced to the bedrock contact, an appropriately sized drive sampler will be driven 2 feet into the claystone bedrock to provide a pilot hole for a 2-foot deep sediment sump. The sediment sump will be a 2-foot-long piece of blank casing installed immediately beneath the screen in all wells. The pilot hole will have a diameter no more than 1-inch greater than the outside diameter (OD) of the casing.

During the drilling process, the center bit will be removed slowly to prevent sand from entering (blowing into) the bottom auger. In the event of sand blow-in, RFP potable water may be added to the inside of the augers to equalize the hydrostatic pressure of the formation water. A record of the amount of water placed in the well will be kept so that it can be taken into account during well development.

The inside diameter (I.D.) of the augers will be approximately 4 inches or more larger than the outside diameter (O.D.) of the casing, resulting in a 2-inch annulus around the casing. Similarly, a 2-inch annulus will be provided around well screens and casings when wells are constructed in open portions of boreholes. In open-hole installation (wells constructed in uncased boreholes), the use of stainless steel casing centralizers will be required to ensure the 2-inch annulus is maintained. Centralizers should be provided above and below the well screen, but not within the bentonite seal. Depending on the well depth and diameter, centralizers may also be required at intervals along the riser to

provide a 2-inch grout annulus. When hollow-stem augers are used, centralizers will only be required if the auger flights are not a sufficient size to ensure a 2-inch minimum annulus dimension on all sides of the screen.

During the drilling operation, the cuttings and formation water from the boring will be placed in waste drums if required (see SOP 1.8, Handling of Drilling Fluids and Cuttings).

Single-cased wells will be used in the alluvial/unconfined aquifer. Double casing will be required for bedrock wells installed in areas of potentially contaminated alluvial groundwater. Surface casing will be installed through the alluvium according to SOP 3.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing.

Boreholes for alluvial and bedrock wells will be drilled according to SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques or SOP 3.4, Rotary Drilling and Rock Coring.

5.3 WELL MATERIALS AND INSTALLATION PROCEDURES

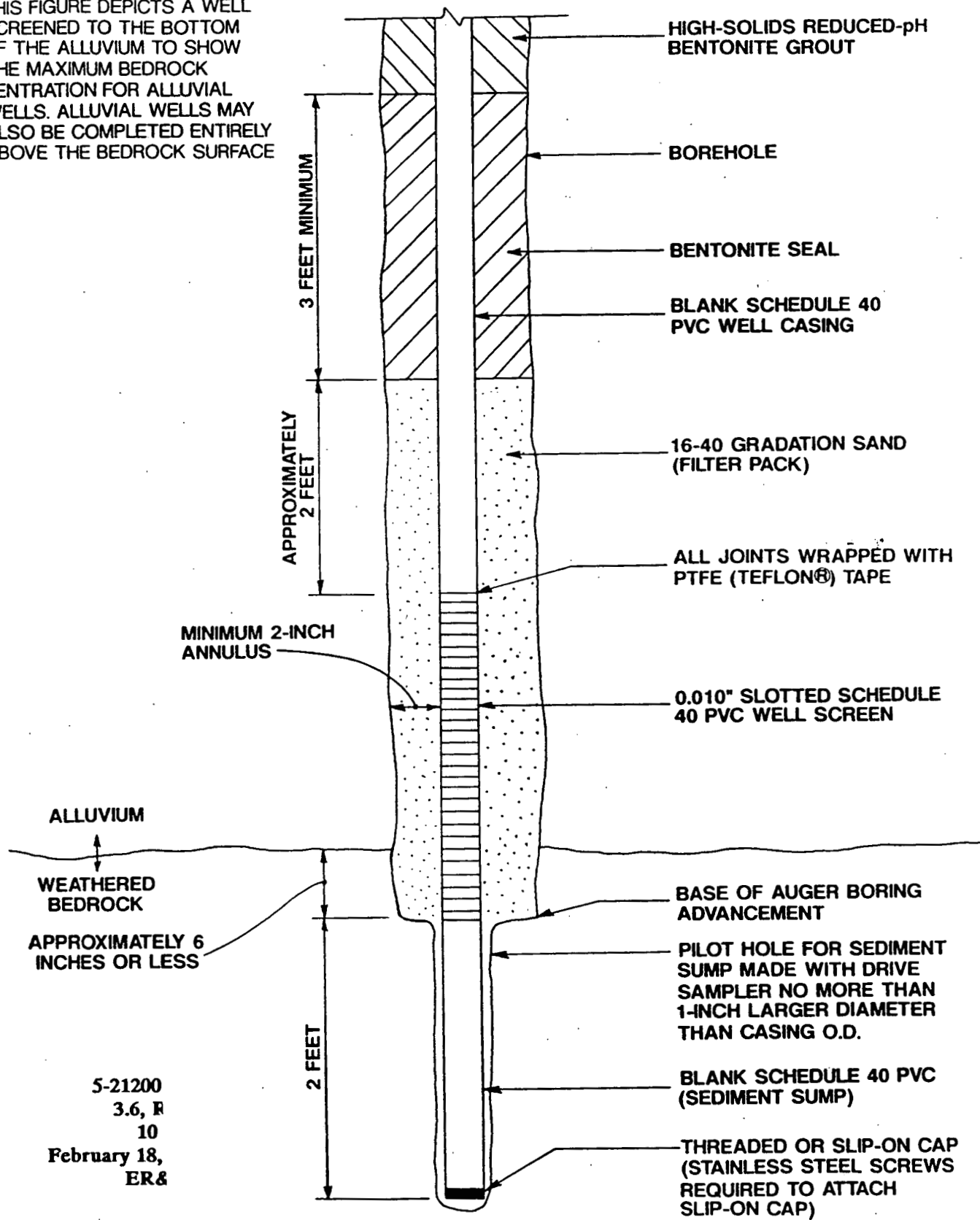
5.3.1 Materials

5.3.1.1 Well Casings

Well casings will consist of new, threaded, flush-joint schedule 40 poly-vinyl chloride (PVC) unless another type of casing (e.g., stainless steel) is required by the FSP or a SOPA. The well casing will extend from the top of the well screen to approximately 2 feet above ground surface. The tops of all well casings will be fitted with slip-on or threaded PVC caps which can be easily removed by hand. All joints within the casing string will be threaded. Heat-welded joints, solvents, and/or gaskets will not be used. Polytetra

NOTE:

THIS FIGURE DEPICTS A WELL SCREENED TO THE BOTTOM OF THE ALLUVIUM TO SHOW THE MAXIMUM BEDROCK PENETRATION FOR ALLUVIAL WELLS. ALLUVIAL WELLS MAY ALSO BE COMPLETED ENTIRELY ABOVE THE BEDROCK SURFACE



NOT TO SCALE

Figure 3.6-1 - SCHEMATIC DIAGRAM OF ALLUVIAL MONITORING WELL COMPLETION

fluoroethylene (PTFE) tape will be wrapped around the joint threads to improve the seal. All well casings will be free of foreign material and will be steam cleaned with approved water before use. Steam-cleaned casings will be stored in plastic sleeves prior to use. Casing with stamped or stenciled nomenclature will not be used.

5.3.1.2 Well Screens

Well screens will consist of new threaded PVC pipe (unless another material [e.g., stainless steel] is required by the FSP or a SOPA) with 0.010-inch factory-machined slots or wrapped screen. All well screens will have an I.D. equal to or greater than that of the well casing. The wall thickness of PVC screen will be the same as that of the well casing. A 2-foot deep sediment sump will be used beneath the screen. A threaded cap or a slip-on cap secured with stainless steel screws will be provided at the bottom of the sump. Well screen with stamped or stenciled nomenclature will not be used.

5.3.1.3 Filter Pack

The filter pack material will be chemically inert, rounded, silica sand of appropriate size for the well screen and host environment. Grain size analyses of the unconsolidated formations underlying the site have indicated a 16-40 gradation is appropriate and will be used on the site unless the FSP or SOPA indicates otherwise. The filter pack will extend approximately 2 feet above the top of the screen unless otherwise specified. The final depth to the top of the filter pack will be measured directly by using a weighted tape measure and not by using volumetric calculation methods. The volume placed will be recorded.

5.3.1.4 Bentonite Seal

A bentonite seal will be installed above the filter pack. The seal will consist of a layer of commercially available bentonite pellets that is at least 3 feet thick when measured immediately after placement, without allowance for swelling.

5.3.1.5 Bentonite Grout

The annular space between the well casing and the borehole will be grouted from the top of the bentonite seal to ground surface. The grout will consist of high-solids reduced pH bentonite grout (American Colloid Pure Gold or approved equivalent) mixed in a powered mechanical grout mixer according to the grout manufacturer's recommendations. The grout will contain at least 30 percent solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. The density will be checked with a mud balance.

Grout will be placed outside of the monitoring well casing using a side-discharge tremie pipe located just above the top of the bentonite seal. The grout will be pumped through the pipe until undiluted grout flows from the annular space at the ground surface. The tremie pipe will then be removed and more grout added to compensate for settling. After 24 hours, the site will be checked for grout settlement and more grout added to fill any depressions. The total volume placed will be recorded.

5.3.2 Installation Procedures

5.3.2.1 Alluvial Piezometer and Monitoring Well Installation

Figure 3.6-1 shows a schematic diagram of the lower portion of an alluvial well completion. Monitoring well installation will begin after formation water and fine grained sediment

have been bailed using a sand bailer until the water is relatively clear and free of sediments. If granular soils do not blow into the bottom auger, raising the augers 1 to 2 feet above the bottom of the hole can help with the removal of muddy water from outside of the augers. This will not work if the hole bottom caves or blows in.

The borehole depth will then be measured to the nearest 0.1 foot, and the well assembly will be measured to the nearest 0.01 foot. The portion of the well casing cut off at the top will be measured and subtracted from the total length supplied to determine the total well assembly length.

Once the well assembly is in place, the filter pack will be added slowly to the zone below the water level in the borehole by tremie pipe. If filter pack material is placed in wells above the water level in the borehole, a tremie pipe will not be required inside of hollow-stem augers. A tremie pipe will be required for all filter placement in open hole completions. The filter pack will be added in 1- to 2-foot increments. Similarly, the augers will be raised in 1- to 2-foot increments so that the sand level is always at or slightly above the bottom of the augers. Depth measurements of the top of the filter material will be taken continuously in the well annulus as the filter is placed. The final depth to the top of the filter pack will be approximately 2 feet above the top of the well screen and will be directly measured by a weighted tape measure. The weight on the measure tape will be stainless steel in the event that it accidentally becomes embedded in the filter pack. If bridging of the filter material occurs in the well annulus or tremie pipe during placement, the bridged material will be broken loose mechanically by shaking augers and/or well assembly. Bridged material in the annulus may also be broken loose by probing with a 1-inch-diameter tremie pipe. If both of these methods are unsuccessful, distilled water may be pumped through the 1-inch tremie pipe to dislodge the bridged material. A record of the amount of water placed in the well will be kept so that it can

be taken into account during well development. The volume of filter material placed will also be recorded.

A minimum 3-foot bentonite pellet seal (before swelling) will be installed immediately above the filter pack. If the bentonite pellet seal will be placed below the water table, it will be installed through a tremie pipe. The bentonite pellets will be added slowly to reduce the chances for bridging of the pellets inside the tremie. The augers will be raised approximately 1 foot above the filter pack prior to adding the bentonite pellets. The top of the bentonite seal should never be above the base of the augers. If the bentonite seal is placed above the water level in the borehole, the pellets may be allowed to free-fall into the borehole if hollow-stem augers are being used. The bentonite will be hydrated using 5 gallons of distilled water after the base of the augers are raised approximately 1 foot above the top of the bentonite seal. The completed bentonite seal will be allowed to hydrate for approximately 30 minutes before proceeding with the grouting operation.

Bentonite grout backfill will be placed from the top of the bentonite seal to the ground surface. The grout mixture will conform to the specifications outlined in Subsection 5.3.1.5, Bentonite Grout. The grout will be tremied into the well annulus using a side-discharge tremie until it is completely full. The volume of grout placed will be recorded. After settlement of the bentonite grout has been allowed for 24 to 48 hours, the protective steel casing will be embedded in cement-bentonite grout or nonshrink concrete. The cement-containing grout will occupy the upper 1 1/2 to 3 feet of the well annulus to anchor the protective casing. This may require removing some of the bentonite grout from the upper 1 1/2 to 3 feet of the well annulus. If the upper grout surface is dehydrated, it will either be removed or rehydrated by adding water and waiting approximately 30 minutes.

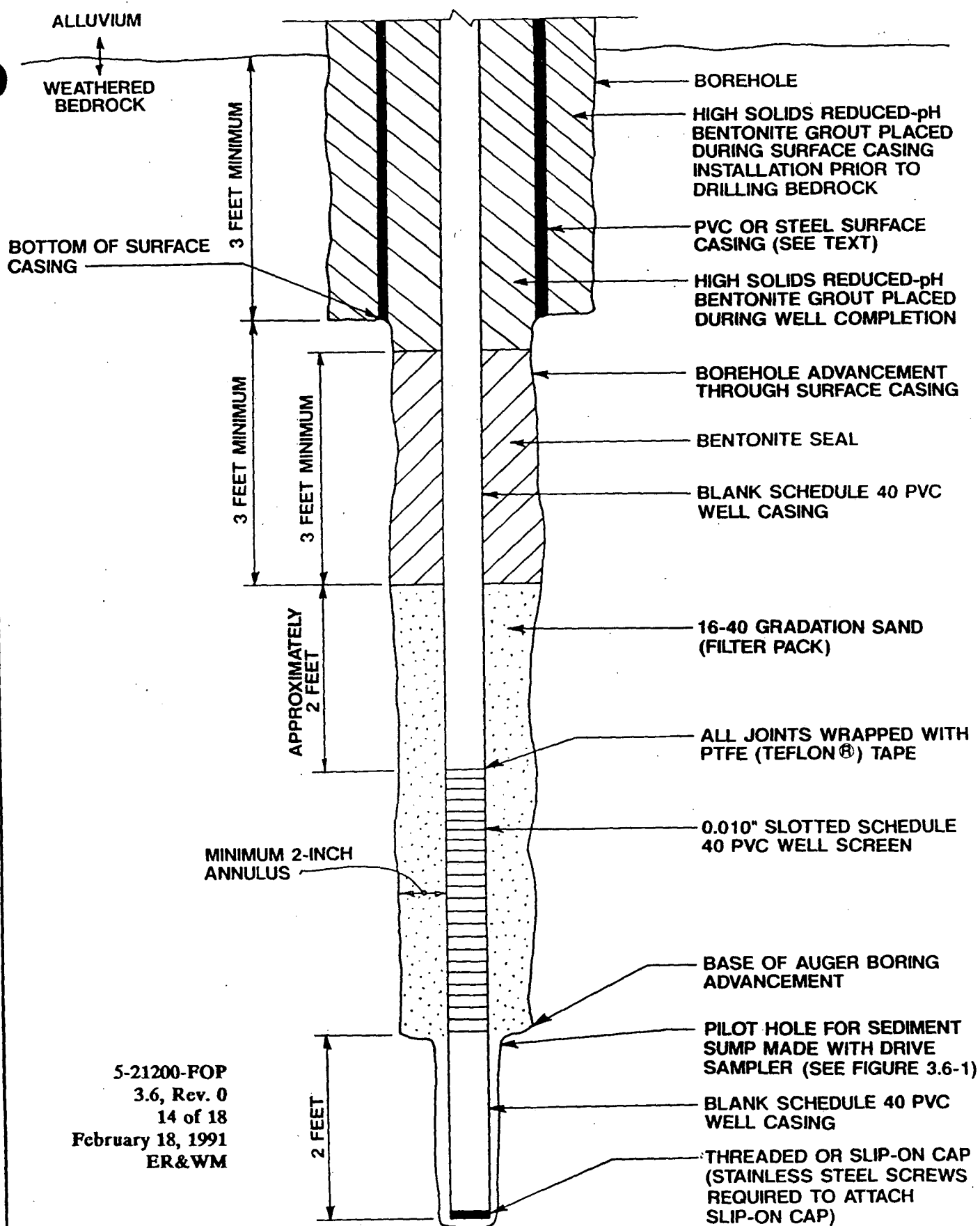
5.3.2.2 Bedrock Piezometer and Monitoring Well Installation

Figure 3.6-2 shows a schematic diagram of the lower portion of a bedrock well completion. Bedrock piezometers and monitoring well installations will be similar to the alluvial well installation procedures except that a surface casing will be provided through the alluvium to guard against potential cross-contamination of bedrock aquifers by contaminated alluvial groundwater. The surface casing will extend from the ground surface to at least 3 feet below the bedrock alluvium contact. This casing will be installed according to SOP 3.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing.

If rotary drilling methods (see SOP 3.4, Rotary Drilling and Rock Coring) are required, the installation procedures will be similar except that the well may be completed in an open hole instead of inside of hollow-stem augers. The well string will be suspended approximately 2 inches above the bottom of the borehole prior to installing the filter pack. This will reduce bending of the well assembly and minimize the potential for collapse of the casing due to the weight of fluid in the annulus. Stainless steel centralizers will be placed at 20-foot-maximum spacing for wells completed in open holes.

5.3.2.3 Well Features at Ground Surface

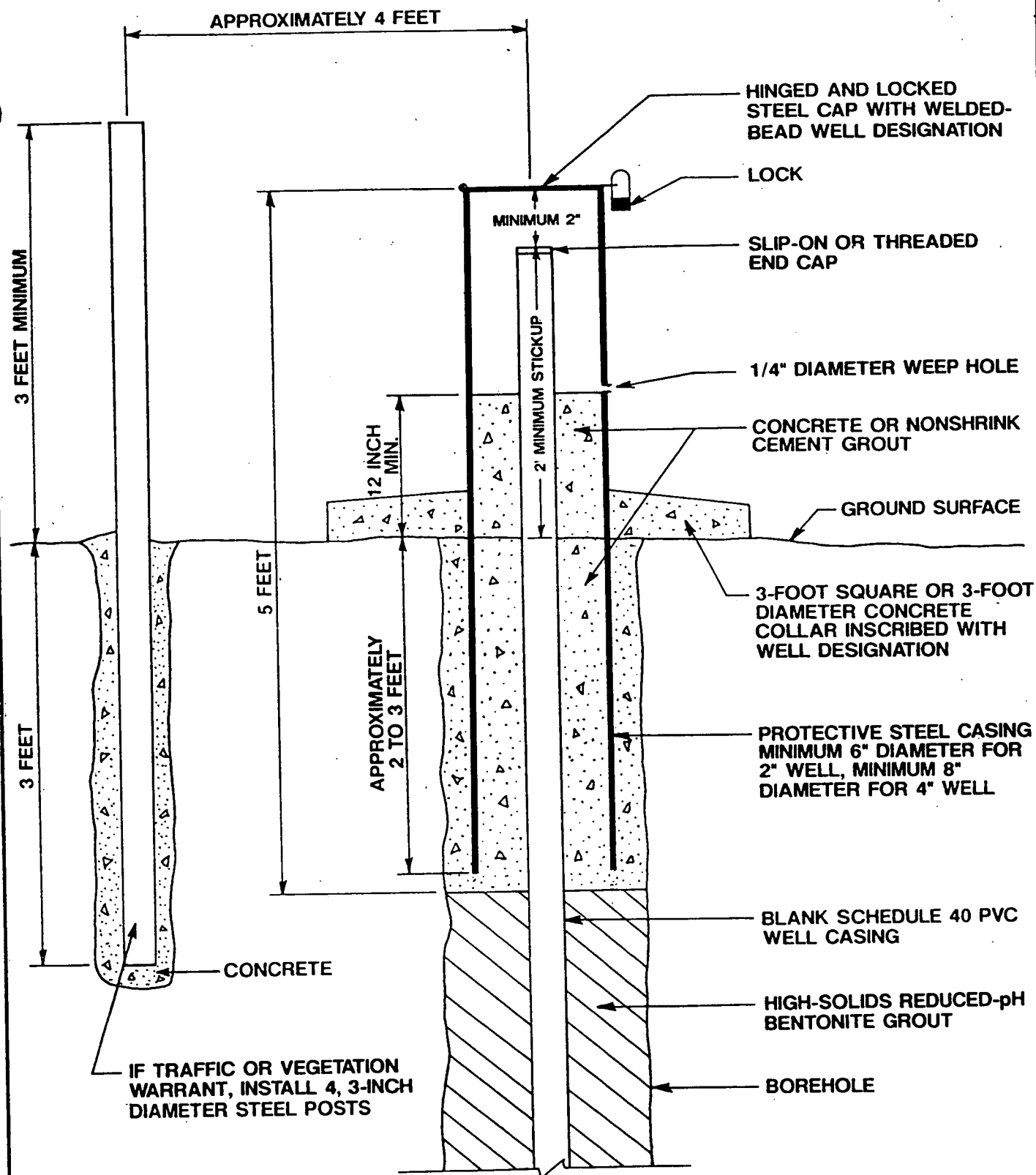
Figure 3.6-3 shows a schematic diagram of well features at the ground surface. A 5-foot-long protective steel casing with a hinged and locking steel cap will be installed over the monitoring well riser that projects above the ground surface between 24 and 48 hours after initial grout placement. The protective casing will have a minimum 8-inch I.D. for 4-inch wells and a minimum 6-inch I.D. for 2-inch wells. The well designation will be welded on the protective casing.



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Figure 3.6-2 - SCHEMATIC DIAGRAM OF BEDROCK MONITORING WELL COMPLETION



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Figure 3.6-3 - SCHEMATIC DIAGRAM OF WELL FEATURES AT GROUND SURFACE

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The bottom of the protective casing will be embedded 2 to 3 feet below the ground surface in concrete or cement grout. Prior to installing the protective casing, the well will be checked for alignment by lowering a 5-foot-long, 1 1/2-inch diameter bailer down the entire depth of the well. If the bailer hangs up, the EG&G project manager will decide whether or not the well needs to be reconstructed.

The annulus between the well riser and the steel protective casing will be filled with nonshrink cement grout or concrete to a minimum of 12 inches above the ground surface, and a 1/4-inch-diameter hole will be drilled in the protective casing just above the grout or concrete surface to allow drainage.

At the same time the protective steel casing is grouted or concreted in place, an external concrete collar approximately 3 feet square will be placed around the protective casing at the ground surface. The well designation will be scribed in the concrete before it sets. The collar will be graded to slope away from the casing in all directions.

When traffic conditions or vegetation warrant extra protection, four 3-inch-diameter steel posts will be installed. The posts will be located radially from the well casing at a distance of approximately 4 feet. They will be embedded in concrete 3 feet below the ground surface with a minimum of 3 feet sticking up above the ground. Installation is required within 48 hours of well installation. In areas of high vegetation, the posts will be flagged.

6.0 DOCUMENTATION

The installation of monitoring wells and piezometers will be documented on groundwater monitoring well and piezometer report forms. Drilling information will be documented on Rocky Flats Plant Borehole Log Forms (SOP 3.1, Logging Alluvial and Bedrock Material) and on hollow-stem auger or rotary and core drilling field activities report forms

(SOPs 3.2 and 3.4) Besides the drilling and borehole information required by these other SOPs, the following documentation will be recorded on the Groundwater Monitoring Well and Piezometer Report Form, Form 3.6A. Location references will use the State Plane Coordinate System and elevations will be feet above mean sea level (USGS datum).

- Elevation of ground surface
- Elevation of top of surface casing/riser pipe
- Height of top of surface casing/riser pipe above ground surface
- Depth of surface seal below ground surface
- Type of surface seal
- Type and size of surface casing
- Depth of surface casing below ground
- Types/depths of centralizers
- Type and size of riser pipe
- Diameter of borehole
- Depth of borehole
- Type/volume of backfill
- Elev./depth top of seal
- Type of seal
- Elev./depth bottom of seal
- Type/volume of filter pack
- Depth of top of filter pack
- Elev./depth top of screened section
- Type of screened section
- Screen openings
- I.D. of screened section
- Elev./depth of bottom of screened section
- Length of blank section below screen

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- Elev./depth of bottom of plugged blank section
- Elev./depth of bottom of sand column
- Type of backfill below observation pipe
- Elev./ depth of bottom of hole

GROUNDWATER MONITORING WELL AND PIEZOMETER REPORT

PROJECT _____ LOCATION _____ Date Completed _____ Original Depth _____ Inspected By _____ Date _____ Checked By _____ Date _____	Page _____ of _____ Well No. _____ Hydrostratigraphic Unit _____ Depth Interval _____
--	--

Elevation of top of surface casing / riser pipe. _____

Height of top of surface casing / riser pipe above ground surface. _____

Depth of surface seal below ground surface. _____

Type of surface seal: _____

I.D. of surface casing. _____

Type of surface casing: _____

Depth of surface casing below ground. _____

I.D. of riser pipe. _____

Type of riser pipe: _____

Diameter of borehole. _____

Depth of borehole. _____

Type/volume of backfill: _____

Elev./depth top of seal. _____

Type of seal: _____

Elev./depth bottom of seal. _____

Type/volume of filter pack. _____

Depth of top of filter pack. _____

Elev./depth top of screened section. _____

Type of screened section: _____

Describe openings. _____

I.D. of screened section. _____

Elev./depth bottom of screened section. _____

Length of blank section. _____

Elev./depth bottom of plugged blank section. _____

Elev./depth bottom of sand column. _____

Type of backfill below observation pipe. _____

Elev./depth of hole. _____

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**TITLE
LOGGING AND SAMPLING OF
TEST PITS AND TRENCHES**

Approved By:

J. W. Langman Jr.

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes equipment, decontamination, and procedures that will be used for field data collection and documentation during logging and sampling of test pits and trenches in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

Open excavations, long and narrow if a trench, or rectangular if a pit, may be used for shallow geological and environmental subsurface exploration and/or sampling purposes. Trenches or pits will be excavated manually or with a machine such as a backhoe, clamshell, trencher excavator, or bulldozer. Samples may be obtained by using a variety of sampling equipment.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel logging and sampling test pits and trenches will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure.

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Soil Sample Collection--Surface. Colorado Department of Health Radiation Counting Facility, Operating Procedure. July 1, 1989.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are:

- SOP 3.10, Borehole Clearance
- SOP 3.8, Surface Soil Sampling
- SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples
- SOP 3.1, Logging Alluvial and Bedrock Materials
- SOP 1.3, General Equipment Decontamination
- SOP 1.4, Heavy Equipment Decontamination

5.0 EQUIPMENT AND PROCEDURES

5.1 MATERIALS AND EQUIPMENT

The following is a list of equipment and materials that may be needed to perform trenching and trench sampling:

- Backhoe (or other appropriate excavation equipment)
- Steam cleaner
- 2- to 3-inch-diameter stainless steel, thin-walled tube (Shelby tube) samplers
- Sample jars
- Extension rods with slide hammer apparatus to drive tube samples
- Teflon® sheeting
- Plastic caps for tube samplers
- Electrical tape
- 4-mil polyethylene sheeting

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- Coolers
- Ice (H₂O or blue ice)
- Sample labels
- Chain-of-custody forms
- Phosphate-free detergent (e.g., Liquinox)
- Tap water
- Distilled water
- Plastic buckets
- Scrub brush
- Stainless steel bowl
- Stainless steel long-handled spoon
- Stakes
- Gridded paper
- Tape measure
- Camera and film (photography is security controlled)
- Photolog form(s) (Form 3.7C)
- Location map(s)
- Compass
- Personal health and safety equipment, as described in the Health and Safety Plan HSP)

5.2 PROCEDURES

5.2.1 Excavation

Prior to excavating, locations will be cleared according to SOP 3.10, Borehole Clearance. All excavations that are deeper than 4 feet must be examined, and measures taken to comply with

OSHA regulations prior to personnel entry. All activities will be conducted in accordance with the Health and Safety Plan (HSP).

Excavated material will be selectively stockpiled near the excavation to allow backfilling of the material in the general order in which it was removed. Material excavated from within an Individual Hazardous Substance Sites (IHSS) will be stockpiled within the IHSS boundaries to avoid expansion of the IHSS. Depending on sampling requirements outlined in the Field Sampling Plan (FSP), samples may be obtained from the excavation bottom at different depths as excavation proceeds, or the pit may be excavated to its final depth and then sampled from the sides.

Pits and trenches will normally be backfilled the same day as excavation, immediately after completion of sampling and/or logging. If pits are left open overnight, the pit and stockpile will be covered and barricaded for personnel safety and prevention of windblown dispersal of soils.

5.2.2 Logging

Classification of soil and rock, and logging of pits and trenches will be conducted in general accordance with SOP 3.1, Logging Alluvial and Bedrock Materials. Reference stakes or reference lines between stakes should be used to help measure the pit dimensions and stratigraphy. If the stratigraphy is consistent around the periphery of the pit or on both sides of a trench, a borehole log may be sufficient to document the conditions. However, if relatively complex conditions are exposed, a sketch of the pit wall(s) should be made to supplement the log form. The sketch will be drawn to scale and indicate the major stratigraphic features exposed in the pit. Any visual signs of contamination will also be noted in the sketch and/or on the log. The pit sketch will include a plan view showing the pit orientation with a north arrow and will indicate the side(s) that is sketched.

5.2.3 Sampling

Prior to sampling, the surface to be sampled (bottom or side) will be peeled with a stainless steel instrument to expose an undisturbed surface. Peeling will remove material possibly cross-contaminated during the excavation process by materials from other depths within the pit. If the trench or pit sides are sampled, peeling will start at the top and proceed downward and then sampling will start at the bottom and progress upward. Alternatively, each sample location may be individually peeled immediately prior to obtaining the sample.

After peeling, sampling will be conducted either by driving stainless steel thin-walled (Shelby) tubes, or by using a stainless steel spoon or scoop, to remove soils from the pit and then placing them in a container. In general, sample containers will be consistent with those described in SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples. However, Volatile Organic Analysis (VOA) samples may be obtained in stainless steel drive tubes and then immediately capped with Teflon®-lined plastic caps sealed with electrical tape.

In the case of radiological contaminant exploration, the FSP may require that several samples be obtained within the upper 1 to 2 inches of the pit. If so, the procedures in SOP No 3.8, Surface Soil Sampling, will be followed for these samples. Prior to sampling each depth, the ground surface will be excavated to the appropriate required depth with a shovel, and then the surface will be peeled with a stainless steel scraper over the required area. In wet or windy weather conditions, precautions will be taken so that the moisture of the samples is not affected by weather and so that windblown dust does not cross-contaminate samples. Depending on the severity of the weather, this may require suspending sampling activities.

5.2.4 Trench Backfilling - Site Restoration

After completion of sampling and logging, the original soils will be replaced in the pit or trench at their original depths to the extent practical so that the soil from the bottom of the trench will be placed on the bottom and the topsoil will be replaced on the top. This can generally be accomplished by replacing the excavated material in layers of less than 8 inches on uncompacted thickness and making several passes over the soil lift with compaction equipment designed to compact soil. Backfill in outlying areas need not be compacted beyond tamping with a backhoe bucket. All excavation will be restored to near original line, grade, and aesthetics.

5.2.5 Surveying

Pit locations will be surveyed either before or after excavation. Surveying will involve obtaining horizontal coordinates of a stake near the center of the pit and an elevation of the ground surface at the stake. Required accuracies are given in the FSP.

6.0 DECONTAMINATION

Excavation equipment will be decontaminated prior to excavating each trench or pit and at the conclusion of the operation. Sampling and peeling equipment will be decontaminated prior to collecting each sample. Care should be taken to inspect and monitor all excavation equipment, especially the backhoe, to ensure that no hydraulic and/or fuel leaks add contaminants to the site.

Specific decontamination procedures are described in SOP 1.3, General Equipment Decontamination and SOP 1.4, Heavy Equipment Decontamination..

7.0 DOCUMENTATION

All information required by this SOP will be documented on the Borehole Log Form (in SOP 3.1, Logging Alluvial and Bedrock Materials); the Field Activities Report, Pits and Trenches Form (Form 3.7A); the Profile Sketch Form (Form 3.7B); and the Photolog Form (Form 3.7C). The Field Activities Report Form will be filled out for each day of excavation at a given location, and, in situations where more than one pit or trench is excavated and completed per day, at least one form will be completed per pit or trench. The Borehole Log Form will include information on subsurface material classification and lithology.

The Profile Sketch Form will show stratigraphy graphically if warranted by the complexity of the conditions exposed. At least one color photograph will be taken of each trench or pit, and multiple photographs will be obtained if conditions vary across the pit or trench. All photographs taken at the RFP must conform to plant security controls. The roll number, frame number, orientation, and location of each photograph will be recorded on the Photolog Form. A visual scale and color reference chart will be included in all photographs. An 8-inch by 10-inch print will be stapled to the photolog form. The Field Activities Report will include the following information and have space for comments and documentation of general observations:

- Project, crew, and borehole identifications
- Weather conditions
- Equipment descriptions (backhoe, shovel, etc.)
- Sampling information (types, depths, locations)
- Site restoration
- Pit/trench horizontal dimensions
- Pit/trench depth
- Chronological record of activities

**PITS AND TRENCHES
FIELD ACTIVITIES REPORT**

PROJECT NUMBER	_____	DATE	_____
PROJECT NAME	_____		
WEATHER CONDITIONS	_____		
EXCAVATION EQUIPMENT	_____		
EXCAVATION IDENTIFICATION	_____		
EXCAVATING CONTRACTOR	_____		
GEOLOGISTS/ENGINEER	_____		
CREW MEMBERS	_____		
WATER LEVEL/TIME	_____		
TOTAL DEPTH/SIZE	_____		
WASTE TYPES, VOLUMES AND DRUMS USED	_____		

SITE RESTORATION	_____		

PIT/TRENCH HORIZONTAL DIMENSIONS/ORIENTATION	_____		

PIT/TRENCH DEPTH	_____		
CHRONOLOGICAL RECORD OF ACTIVITIES	_____		
COMMENTS	_____		

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Scale
PROFILE SKETCH FORM

Orientation _____ Scale _____
Excavation I.D. No. _____ Coords. N _____ E _____
Geologist/Engineer _____ Date _____

- Label - Grain size estimates per stratigraphic unit
- U.S.C.S. symbols
 - True dip & strike estimate of bedding planes, unconformities, faults

U.S. DEPARTMENT OF ENERGY
ROCKY FLATS PLANT

Staple Photo "UP" this edge

PHOTOLOG SHEET

Orientation _____ Time of Day _____ Sun Position _____ Geologist/Engineer _____
Excavation I.D. No. _____ Distance from Wall _____ Date _____ Coords. N _____ E _____

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TITLE:
SURFACE SOIL SAMPLING

Approved By:

J. W. Langmaier

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at Rocky Flats Plant (RFP) to sample near-surface soils. The SOP is divided into two primary sections: one for obtaining surface scrapes according to several protocols for assessing radionuclide contamination (Section 5.0) and another for more generalized sampling of near-surface soils for other nonradionuclide analyses (Section 6.0).

This SOP describes personnel responsibilities and qualifications, sampling equipment and procedures, decontamination, and documentation procedures.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel sampling surface soils will be scientists, engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Colorado Department of Health Radiation Counting Facility Operating Procedure. Version 1.0. "Soil Sample Collection - Surface." July 1989.

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Interim Final. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

Rockwell International Rocky Flats Plant Environmental Restoration Program. Quality Control Plan. January 1989.

The Environmental Survey Manual. DOE/EH-0053. Volumes 1-4. August 1987.

4.2

INTERNAL REFERENCES

Related SOPs cross-referenced in this SOP are as follows:

- SOP 3.2, Drilling and Sampling Using Hollow-stem Auger Techniques
- SOP 3.7, Logging of Test Pits and Trenches
- SOP 1.13, Containerizing, Preserving, Handling, and Shipping Soil and Water Samples
- SOP 1.3, General Equipment Decontamination
- SOP 1.16, Field Radiological Measurements

5.0

PROCEDURES FOR SURFACE RADIONUCLIDE SOIL SAMPLING

There are 3 surface radionuclide soil sampling techniques employed at the RFP: (1) Colorado Department of Health (CDH) method, (2) Rocky Flats (RF) method, and (3) the "grab method." The CDH method will be used in Inter-Agency Agreement (IAG) projects, Environmental Restoration (ER) support for construction work on site, and other DOE related work. The RF method will be used in the annual soil monitoring program

and other specialized projects. The "grab method" will be used in special circumstances when the CDH or the RF methods do not apply. The primary considerations for acquiring surface soil samples for radionuclide analysis include the following:

- Sample handling should be minimized.
- The sample will be placed in an air-tight stainless steel container or wide-mouth plastic container immediately after collection.
- The sample will be properly labeled.
- No sieving of soil material will be performed in the field.

Refer to SOP 1.13, Containerizing, Preserving, Handling, and Shipping Soil and Water Samples for further details. Above-surface plant parts and coarse material (pebbles, rocks, and stones) will be removed by the sampling team. The soil samples will be classified according to SOP 3.1, Logging Alluvial and Bedrock Material. All sampling equipment will be protected from the ground surface with plastic sheeting.

5.1

EQUIPMENT AND MATERIALS

The following is a list of equipment used for radionuclide contaminated soil sampling:

- CDH soil sampler
- Stainless steel scoop
- Stainless steel lab spoon
- Stainless steel mixing bowl or pan equivalent
- Sample containers

- Sample labels
- Wash and rinse tubs
- Phosphate-free detergent
- Distilled water
- Plastic sheeting
- Sample locations (map and/or list)
- Appropriate health and safety equipment
- Logbook

5.2

PROCEDURE

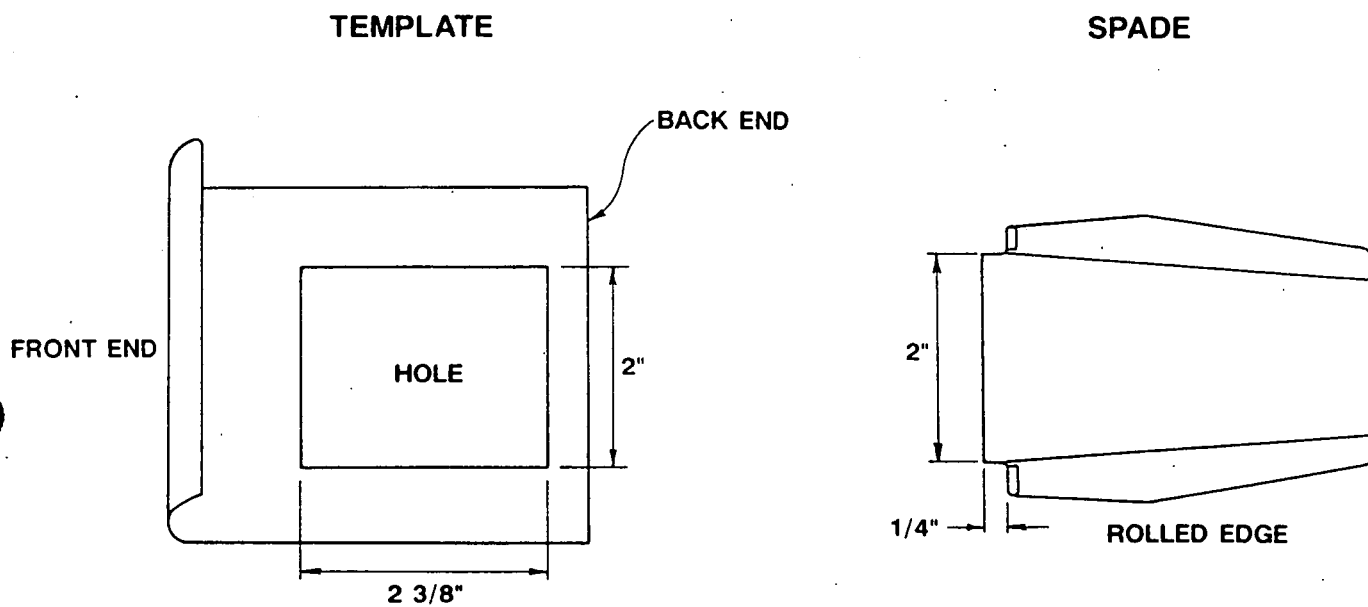
Sampling locations are described in the Field Sampling Plan (FSP). Some samples will be composited to obtain representative samples of large areas and others will be single-location samples. Sampling techniques for either type of sample are the same prior to compositing.

5.2.1

Soil Sampling with a CDH Sampler

The preferred method for collecting soil samples for radionuclide analysis at the RFP is with the CDH sampler that was designed for this purpose. The sampler is designed to obtain a sample from the upper surface 1/4 inch deep from an area 2 inches wide and 2 3/8 inches long, as shown in Figure 3.8-1. The following procedures will be used for the CDH sampler:

1. Always use a clean sample container.
2. Label sample container into which the soil sample is to be placed.



SOIL SAMPLING DEVICE,
CRITICAL DIMENSIONS

Figure 3.8-1

3. Make sure that the soil sampling template is decontaminated and dry, then place it on the ground and push it into the soil so that the soil surface is even with the upper surface of the sampling template.
4. At the back end of the template (the end farthest from the curved scoop at the front of the template), place the sampling spade in the soil 1/4 inch deep, up to the rolled edges on the flanges on each side of the spade, so that the rolled edges face the front edge of the template. Refer to Figure 3.8-1.
5. Gently, but firmly, draw the sampling spade forward, so that the soil is drawn to the curved scoop at the front of the sampling template.
6. Lift the spade, place it at the back of the template again and draw it forward once more to ensure that the entire volume that is defined by the template (1/4 inch deep by 2 inches wide by 2 3/8 inches long) is collected into the curved scoop at the front of the template. Repeat as necessary to obtain a complete sample.
7. Taking care not to spill any of the soil that has been collected, lift the template up from the ground. Place the curved scoop at the front of the template inside the sample container and tip the sampling template up to pour the soil into the container. Brush any soil that adheres to the scoop into the sample container.
8. Close the container.

9. After samples are placed in sample containers, the outside of the container will be wiped clean of excess material and placed in double plastic bags.
10. Transfer the samples to the sample manager.
11. Decontaminate equipment after use and between sample locations. For specific decontamination guidelines, consult SOP 1.3, General Equipment Decontamination. Decontamination according to these procedures is not necessary between composite sample points; however, excess dirt or mud should be cleaned from the equipment.

5.2.2

Soil Sampling with a Jig and Scoop (RF method)

INTRODUCTION

- The purpose of soil sampling can generally be related to one or more specific objectives. These are as follows: (1) deposit inventories; (2) deposition increment; (3) agricultural availability; (4) resuspension availability; and (5) distribution of contaminant.
- Procedures given here include those for inventory and resuspension. Inventory sampling can be performed with shallow samples supported by a suitable number of deep cores. Resuspendable material sampling can be accomplished with 1 cm deep samples.

- If the objective of sampling is other than inventory or resuspension, special collection techniques could be required. When this occurs, the project manager should seek expert advice and record the details of the modified procedure.

INVENTORY SAMPLING

Equipment

- Soil sampling jig (10 X 10 X 5 cm)
- Spare sampling jig parts
- Scoop, stainless steel
- Brushes, wire and paint
- Water supply, detergent, wash bucket and paper towels
- Paint cans, 1 gallon new
- Hammer
- Miscellaneous cold chisels
- Pointed cement trowel
- Marking pens, grease type or felt tip
- Metric rule
- Wood block (10 X 10 X 30 cm)
- Site selection plan
- Log book

PROCEDURE

General

- The purpose of sampling is to determine the amount of accumulated plutonium that has been deposited on the ground. This is accomplished by collecting a sample volume of 5000 cm³ of soil in-situ. The jig outlines a 10-cm square area and is driven 5 cm into the soil to cut three sides of the sample. At the fourth side, soil is removed from outside the jig's perimeter. The scoop is used to finish the cut on both the fourth side of the sample and the bottom surface. Five samples should be collected at each location and composited.
- In very rocky areas, good sample geometry (shape) cannot be achieved with the jig. In those cases, the jig and the metric rule should be used to gauge the desired sample size. Rocks and soil are pried or chiseled out of place for collection.

Selection of Sample Site

- A site selection plan should be used to specify the general site location. The plan must provide adequate information for the sample collection crew to locate each specific site. The sites should be permanently marked with a steel post and identification sign so that the same area can be resampled. Permission to collect samples and mark the site should be obtained from each landowner. The sample collection crew should be accompanied by supervision to ensure that specified procedures are followed.

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- The following site selection criteria should be considered:
 - Undisturbed location for the time interval of interest.
 - Near the center of a large, flat, open area.
 - Not subject to excessive runoff during heavy rain.
 - Light to moderate vegetation and permeable soil.
 - Not in area of mechanical disturbance.
- If a sample site is not available that meets the above criteria, the independent judgment of the crew supervisor should be used to meet the basic objectives as closely as possible.
- All selected sites should be located on a map.

COLLECTION PROCEDURES

Ten soil samples should be collected at each site and composited for analysis. Samples should be collected at the center and corners of two one-meter squares which are spaced one meter apart.

- Place the sampling jig on the ground, and using the wood block and hammer, drive the jig into the soil to a depth of 5 cm.

- With minimal disturbance to the soil inside the jig, use a scoop, trowel or chisel to remove the soil from around the open side of the sample jig. Soil should be removed to a depth which will allow easy removal of the sample.
- Discard the soil removed from outside the jig.
- Remove the soil sample from the interior of the jig with a scoop or trowel and place it in the paint can. Repeat this procedure at each of the five locations and place the samples in the same can to yield one composite sample.
- Label the sample container with the following information:
 - Sample site identification
 - Collection date
 - Name of sample collector
- As an alternate, remove the soil sample from the interior of the jig with a scoop or trowel and place it in a 10-mesh sieve that has a plastic bag attached to the bottom to receive the material that passes the sieve. After all the sub-samples have been placed into the sieve, attach the cover and seal with tape. Shake the sieve for several minutes and discard the oversize soil particles. Place the plastic bag of soil fines in the paint can. Make certain to select a plastic bag that stretches tightly over the rim of the sieve.

5.2.3 Soil Sampling with a Stainless Steel Scoop ("Grab Sample")

Sampling with a stainless steel scoop is similar to the method used with the CDH sampler. However, the exact sample size and depth will be difficult to duplicate.

Follow these procedures for use of a stainless steel scoop:

1. Prepare sample container as previously described.
2. Use the scoop to excavate the soil; depths and volumes may vary depending on field conditions and work requirements.
3. Containerize and handle as previously described.

5.2.4 Compositing of Soil Samples

Compositing of samples will be required for some tasks. This will be done by emptying the sample container(s) into a large stainless steel bowl or pan and stirring by using a stainless steel scoop or spoon to thoroughly mix the sample(s). The soil will be scraped from the sides, corners, and bottom of the pan, rolled to the center of the pan, and mixed. The sample will then be quartered and moved to the four corners of the mixing pan. Each quarter of the sample will then be mixed individually. Each quarter will then be rolled to the center of the mixing pan and the entire sample mixed together. This procedure will be repeated as necessary to provide a homogeneous sample before being placed in the sample container(s).

6.0

PROCEDURES FOR NONRADIONUCLIDE SURFACE SOIL SAMPLING

Soil sampling will be done with either a stainless steel scoop for very shallow samples or with a spade and a stainless steel scoop. The primary consideration for acquiring samples in the field include the following:

- Samples will be stored near 4° C.
- Sample handling should be minimized.
- Sample/air contact should be minimized.
- The sample should be placed in air-tight container immediately after collection.

For further information on sample handling, refer to SOP 1.13, Containerizing, Preserving, Handling, and Shipping Soil and Water Samples, and the task sampling plan.

6.1

EQUIPMENT AND MATERIALS

The following is a list of equipment for nonradionuclide contaminated soil sampling:

- Spade (long handle)
- Mason trowel
- Stainless steel scoop
- Stainless steel lab spoon
- Sample labels
- Sample containers
- Wash/rinse tubs
- Phosphate-free detergent
- Distilled water

- Plastic sheeting
- Locations (map and/or list)
- Appropriate health and safety equipment
- PID (Photoionization detector) or FID (flame ionization detector)
- Logbook
- Ice chest

6.2

PROCEDURE

The following procedures will apply for surface soil sampling with a spade and scoop:

1. Carefully remove vegetation and any undesirable top layer of soil to the desired sample depth with a decontaminated steel lawn or garden spade.
2. Using a decontaminated stainless steel scoop or trowel, remove and discard the thin layer of soil from the area that contacted the shovel.
3. Using decontaminated tweezers or forceps, remove debris and coarse materials such as pebbles, rocks, and stones.
4. Transfer the sample into an appropriate sample container with a stainless steel lab spoon or equivalent
5. Label the sample container with the appropriate sample information including: date and time, the sampler's initials, the sample identification, and sample location. Record on the field data collection form. Handle samples according to SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples.

7.0

DECONTAMINATION

In general, sampling equipment will be decontaminated between individual sampling points to minimize potential cross-contamination. Complete decontamination is not required between composite sample points; however, excess dirt or mud should be wiped from the sampler after each sample.

Detailed decontamination procedures are in SOP 1.3, General Equipment Decontamination.

8.0

DOCUMENTATION

Form No. 3.8A, Surface Soil Data Collection form, will be filled out for each sample location and for composite sample with the northwest corner of the composite area for the X, Y location. The information needed includes sample number, date, time, location code, quarter, purpose, sample location, composite information, QC sample information, collection method, sampling team members, volume collected, head space reading, COC number, analysis requested, matrix, and the shipping date for the sample. Form No. 3.8B, Rocky Flats Field Activities Report Surface Soil Sampling, should be used for collection of samples for compositing. The form should include project identification, date, sampler, location, grid description (10-acre plot and grid location within), time, and equipment decontamination.

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TITLE:
SOIL GAS SAMPLING AND
FIELD ANALYSIS

Approved By:

J. W. Langman

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at Rocky Flats Plant (RFP) to conduct soil gas field surveys or headspace measurements of organic vapors in environmental samples. It also provides procedures for dynamic and passive collection of soil gas samples to be used in identifying volatile organic compounds (VOC) present at Individual Hazardous Substance Sites (IHSS) on the RFP site. The requirements for application of these procedures to a given site will be specified in applicable project plans.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel performing VOC field surveys and/or monitoring with flame ionization detector (FID) or photoionization detector (PID) portable vapor meters, and/or collecting soil gas samples will be scientists, engineers, or field technicians with appropriate field experience and training provided under the supervision of another qualified person.

Only qualified personnel will be allowed to operate portable gas chromatographs (GCs) or vehicle-mounted GCs in mobile laboratories. Required qualifications vary depending on the activity to be performed. In general, qualifications will be based on education, previous experience, on-the-job training, and supervision by qualified personnel. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

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4.2 INTERNAL REFERENCES

Related SOPs cross-referenced in this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 1.13, Containerizing, Preserving, Handling and Shipping of Soil Water Samples

- SOP 1.15. Use of Photoionization Detectors (PID) and Flame Ionization Detectors (FID)

5.0 PROCEDURES AND EQUIPMENT

The concentration of a Volatile Organic Compound (VOC) in soil gas is a complex function of the distribution of the organic compound and its interaction with the soil. This interaction depends on a number of soil parameters including soil particle size and mineralogy, soil lithology, heterogeneity, organic content, moisture, and temperature.

Volatile organic contaminants in soils above the water table (vadose zone) can be present in the gas phase in unsaturated pore spaces, in the water contained in the unsaturated soils, and sorbed on the soil particles. The VOC contamination is the sum of the VOCs contained in all three phases. The partitioning of the VOC between gas, liquid, and adsorbed phases is dependent on both the soil properties and the chemical properties of the compound. Thus, given the chemical properties of the VOC and measurements, or reasonable estimates, of relevant soil parameters, soil-gas data can be used to provide semiquantitative estimates of the VOC contamination in soils.

The sampling and analysis of soil gas can be used as a rapid field screening technique for health and safety evaluations of potentially contaminated soils, to aid in the placement of monitoring wells, to identify VOCs, to evaluate the areal extent of soil contamination, and to estimate the effectiveness of remedial measures.

The sampling and analysis of soil gas can be performed by several different methods. A field survey of work sites and materials can be performed using a portable organic vapor meter. The field survey provides information on total organic vapor concentrations in the air around the work site. A more detailed analysis on the location of VOC contaminated soil may be accomplished by performing field measurements of soil headspace samples. This

technique allows the measurement of the total organic vapor concentration from a specific soil sample. Soil gas samples may also be obtained by pumping directly from a probe inserted in the ground collecting the gas, and analyzing it. This technique of in-situ soil gas sampling allows for the identification and quantification of specific volatile organic compounds.

This procedure will discuss the methods used for the following types of soil gas surveys:

- Field surveys
- Field measurements of headspace samples
- In-situ soil gas sampling
 - Dynamic
 - Passive

5.1 FIELD SURVEYS

Field surveys of work sites, site activities and site materials for volatile organic vapors will be accomplished by using direct reading instruments, such as the photoionization detector [PID] portable vapor meter and the flame ionization detector [FID] portable vapor meter. Field surveys will be used as rapid field screening techniques for health and safety, and for site evaluation before and during the excavation of potentially contaminated soil. These procedures may be used to aid in the placement of monitoring wells, and in the evaluation of the areal extent of soil contamination.

5.1.1 Equipment

- Portable PID or FID

- Calibration gas standards of known concentration (specified in SOP 1.15, Use of Photoionization Detector [PID] and Flame Ionization Detector [FID])

5.1.2 Instrument Calibration and Operation

See SOP 1.15, Use of Photoionization Detector [PID] and Flame Ionization Detector [FID], for instrument operational and calibration requirements.

A factor which will affect total organic vapor concentration measurements is the type of detector which is used (e.g. FID vs. PID). Generally, the FID will be most appropriate for aliphatic hydrocarbons and certain oxygenated solvents while the PID will be more sensitive to aromatic and halogenated hydrocarbons. PID lamps of different ionization energies will respond with varying degrees of sensitivity to the same gases, and are significantly affected by high humidity. Generally, the FID response is proportional to the number of carbon-hydrogen bonds and can therefore be used to estimate concentrations of total hydrocarbons.

5.1.3 Survey Procedures

The following procedures will be used to measure compounds detectable by PID and/or FID in performing field surveys:

1. Check battery charge. Batteries should be recharged for the time frame specified in the operating manuals for both the PID and FID instruments. Usual length of operating time between charges is 8 to 12 hours.
2. FID fuel and/or combustion air-supply gauges should be monitored to ensure sufficient gas supplies.

3. Hold instrument probe close to area to be sampled. The low flow sampling rate of the instrument provides only localized readings. Use a slow, sweeping motion to prevent the bypassing of variable concentration areas, and to allow for instrument response lag time.
4. Record observations, PID and/or FID measurements, source location and description, date, time, weather, sample ID, operator and other pertinent information in the field book. Perform routine maintenance, as described in detail in operating manual, to continue to achieve representative readings. Clean sample probe and/or in-line filters (in front of detector) when high background readings are exhibited after prolonged use. Use of pipe cleaners or clean air blown backward through filters is normally adequate. Do not use organic solvents.

5.2 FIELD MEASUREMENTS OF HEADSPACE SAMPLES

The field analysis of soils for organic vapors can be enhanced by obtaining a sample of contaminated soil, placing the soil sample in a confined space, and allowing volatilization of organic compounds, followed by collection of a sample of the air space above the soil sample. This is referred to as headspace analysis, and is accomplished by half-filling a sample container with a soil sample to be analyzed. VOCs present in the soil pores will diffuse into the remaining unfilled air space within the container at approximately the same concentration as in the soil sample. Physical characteristics of the soil (e.g., temperature, grain size, moisture content, organic carbon content) may have a significant affect on the headspace analysis results, and, therefore, estimates of these parameters should be recorded at the time the measurement is taken. If a photo or flame ionization detector is used for the headspace analysis, record the results on the appropriate forms, Form 3.9A or 3.9B..

Headspace analyses are useful in that they can provide real-time data to aid in soil removal operations, where decisions regarding the extent of soil excavation and its disposal must be determined on-site. In addition, headspace analyses of soils encountered during investigations can be screened for health and safety purposes.

5.2.1 Equipment

- Portable PID or FID
- Calibration gas standards of known concentration (specified in SOP 1.15, Use of Photoionization Detector [PID] and Flame Ionization Detector [FID])
- Split-spoon sampler, hand auger, or other soil sampling apparatus
- Wide-mouth sample jars with screw-cap lids
- Aluminum foil

5.2.2 Instrument Calibration and Operation

See SOP 1.15, Use of Photoionization Detector [PID] and Flame Ionization Detector [FID], for instrument operational and calibration requirements.

A factor which will affect total organic vapor concentration measurements is the type of detector which is used (e.g. FID vs. PID); see Subsection 5.1.2 for discussion.

5.2.3 Sampling Procedure

The following procedure will be used to measure those compounds present in the container headspace detectable by an FID/PID:

1. Collect soil sample using a split-spoon sampler, hand auger or other apparatus which will yield a soil core or intact sample. Be careful not to disturb the sample soil during sampling since doing so may release VOCs that are present. Half-fill a wide-mouthed sample jar with the soil sample. Cover the container opening with aluminum foil and screw the jar lid down tightly. Granular soils should be broken apart by shaking the jar. Cohesive soils should be broken by crushing the sample as it is placed in the jar, and quickly covering.
2. Let the sample sit for 1 hour at ambient temperature before taking reading. If the sample is collected during cold weather when ambient temperatures are below 25°C, or if more immediate results are desired, the volatilization process should be accelerated by placing the container into a warm environment, such as near a vehicle's air heater or in a warm-water (70-degrees Fahrenheit) bath for approximately 30 minutes.
3. Following the warming period, remove the jar lid and insert the probe of the FID or PID through the foil cap (by making a hole in the foil just large enough to accept the probe), and take a reading.

5.3 IN-SITU SOIL GAS SAMPLING

In-situ soil gas sampling is performed by pulling air samples with a vacuum pump directly through a hollow probe in the ground. Analysis of samples can be accomplished by multiple methods. This technique allows for the identification and quantification of specific volatile organic compounds.

In-situ soil gas samples can be collected by dynamic or passive methods. Dynamic soil gas sampling involves extracting a volume of soil gas from the ground and analyzing the sample. A hollow steel rod is driven into the ground, and the soil gas sample is withdrawn with a vacuum extraction pump. The major advantages of dynamic soil gas testing are rapid data availability and the ability to distinguish between soil and groundwater contamination sources by vertical soil gas profiling.

Passive soil gas sampling generally involves implanting adsorption devices in the shallow surface soil and allowing them to adsorb VOC vapors from the soil for a period of days or weeks. After exposure, the devices are dug out and sent to a laboratory for analysis. This sampling methodology is probably the least expensive, but requires a considerable amount of time, and is less versatile than dynamic sampling methods.

Pertinent site-specific and compound-specific factors which influence the collection and interpretation of soil gas are required to be identified and evaluated in order to develop a comprehensive sampling program.

Sampling along an established grid is recommended at sites where the source(s) or general orientation of a subsurface plume are unknown. Where data are available which identify the source areas or plume characteristics, delineation of contaminant edges is most effectively achieved by establishing a transect parallel to the direction of (groundwater) flow and sampling outward from the suspected source. Soil gas probes should not be located less than 50 feet apart because the resolution of most soil gas techniques can be exceeded.

In order to effectively design the soil gas surveys and interpret the results, the subsurface transport and fate of VOCs should be considered. These factors can have a significant affect on the presence and concentration of VOCs in the soil atmosphere. Both physical and microbiological processes can influence soil gas investigations.

Partitioning of the contaminant between gaseous and aqueous phases is the physical process which permits contaminants mixed with water below the surface to be detected in soil gas. The air-water partitioning coefficient can be dependent on both the vapor pressure and aqueous solubility of a compound. Generally, low molecular weight organic compounds (i.e., hydrocarbons, halogenated hydrocarbons, ketones) are most readily detected in soil gas. Compounds possessing vapor pressures less than 1 mm Hg at 25°C will probably not be detected in soil gas. Vapor pressures provide an estimate of the diffusion coefficient and, thus, the "mobility" of the compound in the gas phase.

Soil gas analyses are highly quantitative and specific for individual compounds, but the extrapolation to groundwater contaminant concentrations are not quantitative. Soil gas measurements usually represent an indirect measure of the parameter of interest (e.g., groundwater plumes, extractable hydrocarbon concentrations in soil, sources of subsurface leaks). Variables such as geology, soil moisture content and the air/water partitioning coefficient of the particular contaminant all affect the relationship between soil gas concentrations and groundwater contaminant concentrations. Water, either in the vadose zone (i.e., a very wet clay or a perched water zone) or in the saturated zone (a contaminated zone below clean water), is the major impediment to vapor movement. Soil gas techniques are relatively ineffective for confined aquifers or soils overlain by strata that are impermeable to gas diffusion.

5.3.1 Dynamic Sampling

Dynamic soil gas sampling investigations can be performed using either hand-driven or mechanically-driven probes and relatively inexpensive field instruments or sophisticated laboratory equipment. These techniques require the installation of a probe or soil boring in the vadose zone of a soil followed by withdrawal of the soil gas by a vacuum pump. Soil gas samples may be collected in gas sample bags, syringes, or on adsorption media. Samples collected in gas sample bags or on adsorption media must be analyzed at a nearby or on-site

laboratory due to short sample holding times. Syringe samples must be analyzed on location immediately after collection.

A procedure for sampling of soil gas and on-site volatile organic compounds analysis by modified EPA Method 502.2 is presented in Appendix A as a reference.

5.3.1.1 Soil Gas Probe Installation

Dynamic or grab sampling techniques require the installation of a probe in the vadose zone of a soil followed by withdrawal of the soil gas by a vacuum extraction pump. The probes are usually constructed of 1/4 to 1 inch diameter steel pipe and are equipped with perforations near the tip, or with a detachable drive point. Soil gas probes must be cleaned with steam or hot water and soap before use (see SOP 1.3, General Equipment Decontamination). A sufficient number of interchangeable sampling components should be available so that decontamination does not need to be performed in the field.

Multiple soil gas sampling intervals may be sampled at a one location in order to identify contaminant profiles. The soil gas sampling can also be performed in augured boreholes or through the center of hollow-stem augers by driving the probe at least 2 feet deeper than the augured depth.

Required Equipment and Apparatus

- Soil gas probe(s), tips (if needed), and drive pipe(s)
- A manual or powered probe driver that is able to drive the probe into the ground and remove the probe after a sample is taken
- Vacuum pump with gauge to extract soil gas

- Hammer drill capable of drilling through asphalt and concrete (if required)
- Power source for hammer drill, power probe driver, and vacuum pump
- Adaptor for soil gas probe with appropriate valves and tubing

Procedures

1. Clear the area to be sampled for utilities, cables, pipes, etc. Clear the surface area to be sampled of grass, leaves, and debris.
2. Using a manual or mechanical driver, drive a cleaned/decontaminated probe with drive pipe(s), as needed, into the ground to the desired depth (minimum is usually 3 feet). Probes placed in augured boreholes should be driven at least 2 feet deeper than the augured depth. If refusal occurs significantly before the sampling depth is reached, remove the probe. Clear another sampling point within 1 foot of the first point and drive a clean probe again. If refusal occurs, eliminate the area within 10 square feet as a sampling point.
3. Once the sampling depth is reached, an entry on to the Soil Gas Survey Form (Form 3.9D) and the Soil Gas Survey Map (Form 3.9C) should be made denoting the depth, time and location of the sample. The probe should then be lifted 1-2 inches to expose the air sampling slots in the drive point.
4. Attach adaptor with tubing and stainless steel sampling manifold to the top of the probe/driving pipes

5. Connect adaptor tubing to vacuum gauge on the low-pressure side of the vacuum pump. An in-line liquids trap, programmable mass flow controller equipped with a solenoid valve and timer are very useful additions, but are not required
6. Run vacuum pump to purge system and displace the ambient air in the soil gas probe, drive pipe(s), and tubing before sample collections
7. Purge probe and silicone rubber tube connecting system. The vacuum gauge installed on the low-pressure side of the vacuum pump will be used to evaluate whether a representative soil gas sample can be withdrawn from the subsurface. Generally, if the applied vacuum exceeds 12 inches of mercury, the soil is either water saturated or does not have a sufficient air-filled porosity to produce a meaningful sample.
8. Collect samples from tubing/manifold on the low-pressure side of the vacuum pump
9. Record time vacuum pump is operated before sample collection, and pressure reading (vacuum gauge) of gas in the soil gas probe line, at the time of sampling
10. The drive pipe(s) and soil probe should be removed at each location after the soil gas has been analyzed. The hole should be backfilled if necessary with a native soil or a soil/bentonite mixture to avoid creating a migration pathway. After the removal of the soil probe, the distance between the sampling location and a known point should be measured and recorded on the soil gas survey map (Form 3.9C) and a flag left at the sampling location for subsequent surveying.

5.3.1.2 Sampling for Total Organic Vapor Analysis

In the simplest sampling/analysis technique, an organic vapor monitor such as a PID or FID is used. A piece of tubing of appropriate length is attached to the probe adaptor manifold and the PID/FID. A direct reading of the soil vapor gas total organic concentration may then be made after the PID or FID instrument has pumped sufficiently for the gas sample to reach the detector.

Required Equipment and Apparatus

- Field analytical instrument capable of detecting total organic vapors such as a flame ionization detector (FID) or photoionization detector (PID)
- Accessory tubing between instrument and manifold (maximum length 12 inches)

Collection and Analysis Procedures

1. After purging system, attach sampling tube to manifold valve port from instrument and open manifold valve
2. Allow instrument to pump for a sufficient length of time to displace the ambient air in the sampling tube and instrument before taking reading

5.3.1.3 Sample Collection for Laboratory Analysis

Sampling/analysis of grab samples may also be accomplished by pumping the soil gas from the probe and collecting the gas in a Tedlar bag. Alternatively, the soil gas may be pumped

through a charcoal or Tenax trap. The VOCs in the soil gas are adsorbed onto the charcoal or Tenax. These samples must then be analyzed at an on-site laboratory since the holding times for these collection methods are short (1 to 8 hours). Analytical methods typically include the use of gas chromatography (GC) and/or mass spectrometry (MS).

Specific analytical methods and calibration procedures, standards concentrations, detectors, temperature programs, etc. are dependent on the method of analysis and analytes of interest. Specific analytical methods and procedures will be detailed in applicable project work plans.

Required Equipment and Apparatus

- Gas collection bags such as Tedlar, or carbon sorption or Tenax sample tubes with accessory tubing (if required)
- Low-flow air sampling pumps, such as Gillian (if required)
- Adapter for the soil gas probe with appropriate tubing
- Vacuum pump to extract soil gas

Collection and Analysis Procedures

1. Run vacuum pump to purge system and displace the ambient air in the soil gas probe, drive pipe(s), and tubing. Attach a Tedlar bag and unclamp the flexible tubing, collecting the gas sample in the bag. The bag is then disconnected, sealed, and transported to the laboratory for analysis.

2. To collect sample by adsorption, insert Tenax trap or other sampler into sample chamber and attach to manifold after probe and adaptor system have been purged. Divert soil gas flow through sample chamber. Record flow pressure, elapsed time, and volume of flow, if mass flow controller is used.

5.3.1.4 Sample Collection for Field Gas Chromatographic Analysis

An alternative grab sampling technique requires soil gas to be pumped through the soil probe, collected with a syringe, and immediately injected into a field gas chromatograph or a gas chromatograph located near the sampling site. This method allows for real-time results, and is particularly useful.

Specific analytical method calibration procedures, standards concentrations, detectors, temperature programs, etc. are dependent on the method of analysis and analytes of interest. Specific analytical methods and procedures will be detailed in applicable project work plans.

Required Equipment and Apparatus

- Mobile or field gas chromatograph (GC) and associated support equipment required to properly operate the GC
- A power source and an enclosed area for the GC
- Appropriate calibration gas standards for the GC and all associated equipment needed to perform the calibration
- Sample containers with septum

Collection and Analysis Procedures

1. Collect soil gas sample with a glass syringe by inserting the syringe into the extraction line near the top of the soil gas pump, on the intake side of the pump (See Figure 3.9-1).

5.3.2 Passive Sampling

While other passive techniques may be available, this procedure is directed toward the use of Petrex tubes as the representative technique since their utility has been demonstrated in past studies at Rocky Flats Plant (RFP). The Petrex passive sampling technique is a direct method for trapping and identifying VOCs emanating from either soil (vadose zone) or groundwater contaminated locations. The collector consists of highly sensitive sorbents (such as activated charcoal) chemically fused to the tip of a wire. The collectors are arrayed, generally in a grid pattern, throughout the survey site, normally at a depth of approximately 1 foot (Figure 3.9-2). The collectors reside for a measured period which can range up to 30 days to assure time-integrative gas collection (as opposed to instantaneous collection with grab samples). The collectors are retrieved following the time-integrative collection period, and are then sent to a laboratory for analysis by mass spectrometry.

The most critical aspect of collector placement is to prevent exposing the collector to contaminants other than those in the soil gas. Smoking around the collectors, even when sealed, may contaminate them. Hands must be kept free of organics, including insect repellent, sunblock, gasoline, motor oil, cosmetics, smoke residues, etc. The lip and inside of the tubes, caps, and cap liner must not contact any contaminants. The tubes must be stored in a clean area away from contaminants. They must not be stored near gasoline cans, oily rags, etc., or in areas where exhaust fumes or cigarette smoke is present.

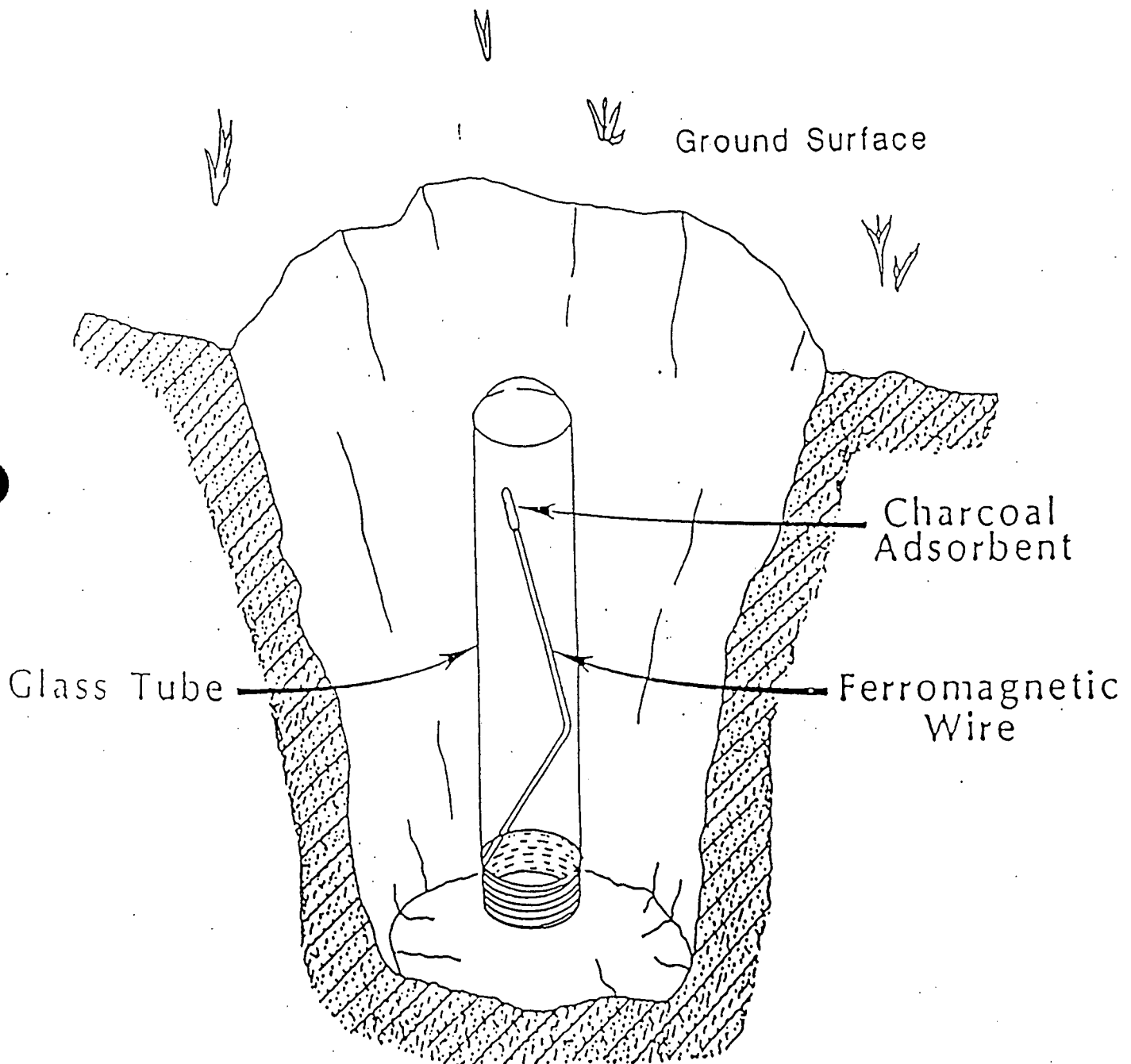


FIGURE 3.9-1

SOIL GAS SAMPLING PROBE AND ADAPTER

SOIL GAS SAMPLING PROBE AND ADAPTOR
 (TAKEN FROM MARRIN & THOMPSON, 1987)

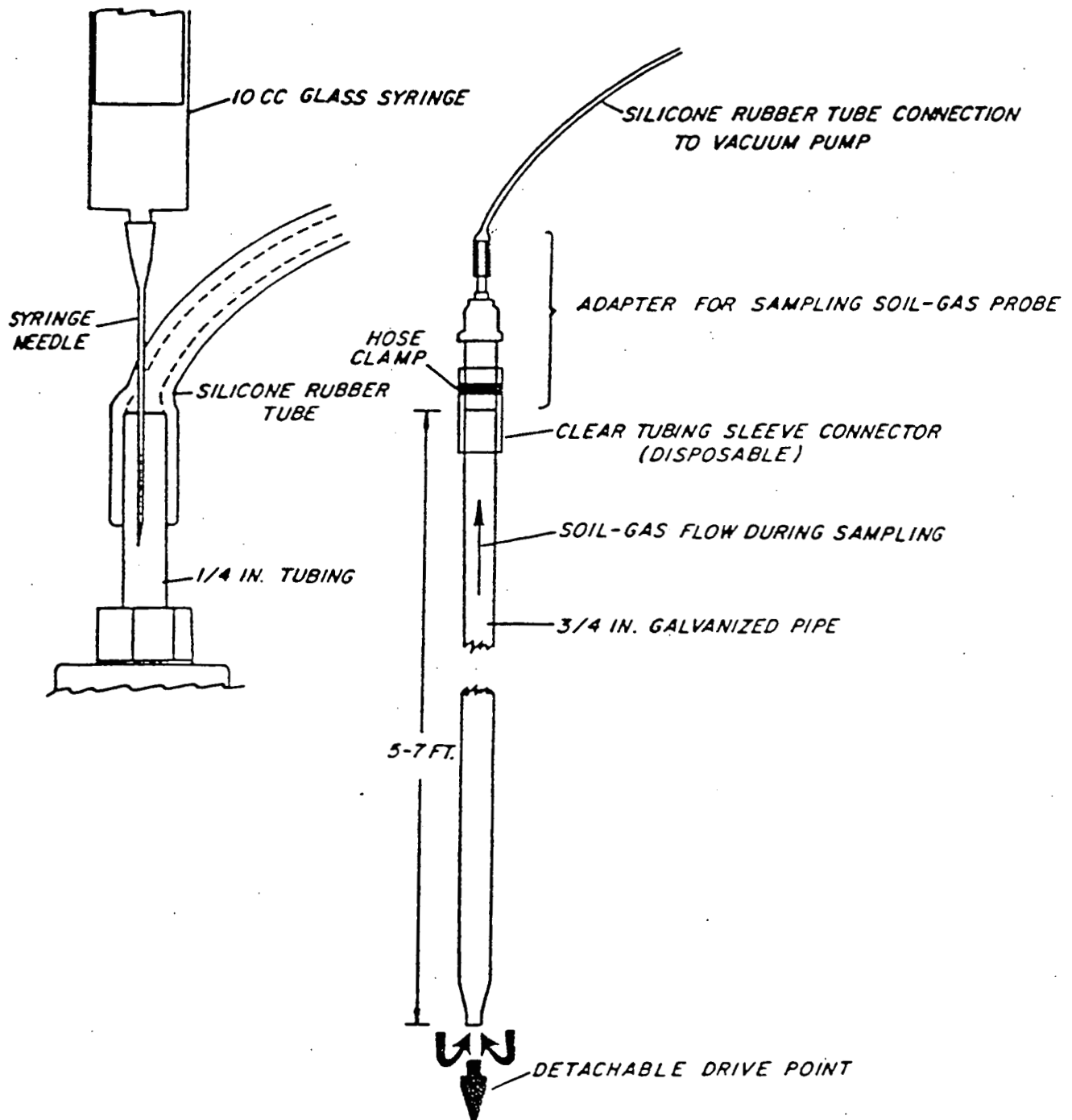


FIGURE 3.9-2

PETREX PASSIVE SAMPLING COLLECTOR

53.2.1 Required Equipment

- Hand auger, slide hammer, shelby tube, etc. or some other hole maker
- Petrex tubes

53.2.2 Installation and Collection Procedures

1. Clear the surface area to be sampled for shallow utilities, cables, pipes, etc. Clear the area to be sampled of grass, leaves, or debris; be careful not to walk or drive over the area.
2. Using a cleaned/decontaminated tool, make a hole into the ground to the desired depth (usually 10-12 inches). If refusal occurs significantly before the sampling depth is reached, remove and clean the tool. Clear another sampling point within 1 foot of the first point and insert the hole maker again. If refusal occurs, eliminate the area within 10 square feet as a sampling point.
3. Dig sample location 10-12 inches deep and approximately 2-4 inches in diameter. Do not contaminate the soil.
4. Unwrap a Petrex sampling tube and remove the cap and black seal liner. Immediately place sampler (vertically with open end down) into sample location hole. The sampler tube must be at least 2 inches below ground surface. Immediately cover the sampler with soil (see Figure 3.9-2).
5. If the black liner has come out of the cap, replace it and return the cap to one of the clean plastic bags provided.

6. Mark the sample location with flagging or other type of locator. Note the sample location on a base map and enter information on Form 3.9C, and in a field notebook.
7. Retrieving samples - (should be done at recommended time intervals).
 - a) Remove the soil until tube is exposed.
 - b) Take the cap from sealed plastic bag. Check for black liner inside cap. If liner has fallen out, replace it.
 - c) Remove tube from the hole. If wire falls out of tube or if tube is broken, use tweezers to handle wires.
 - d) Wipe off the tube and threads thoroughly with a clean, dry cloth. If the tube threads and lip are not properly cleaned, the cap will not seal and the sample will become contaminated.
 - e) Seal tube with cap making sure the black liner is seated to tube lip. If cap does not thread easily, use a different cap. Cap must be sealed tightly against liner.
 - f) Place sticker on cap top and number. Number sequentially starting with 1. Use only numbers to identify samples. Use only one number per tube. Underline all numbers for easy identification. Do not duplicate cap numbers. The Petrex tube distributor, Northeast Research Institute, Inc. (NERI), will number all second and third wire tubes appropriately.

- g) Record number or numbers of sampler corresponding to location on base map and field notebook. Also, record in field notes any samples which have more than one wire per tube.
 - h) Do not place tape, sticker, or glue on glass tube. Stickers provided will adhere if placed on dry cap.
- 8. When packaging exposed tubes, do not use styrofoam or popcorn packing as this can potentially introduce a contaminant. Enclose tubes in two plastic bags and wrap each package tightly with bubble wrap. Complete NERI-WEST Submittal Forms, provided by NERI, to be shipped with samples. Samples are to be placed in sealed containers. Packaging, labeling, and preparation for shipment of field logbook and chain-of-custody will follow procedures as specified in SOP 1.13, Containerizing, Preserving, Handling and Shipping of Soil and Water Samples.

6.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality Assurance (QA) and Quality Control (QC) activities will be accomplished according to the Quality Assurance Project Plan (QAPjP) and the project specific Quality Assurance Addendum (QAA).

In addition to adhering to the requirements of the site-specific Field Sampling Plan (FSP) and any supplementary site-specific procedures, the minimum QA/QC requirements for this sampling activity are the following:

- QC Samples -- The number and types of QC samples including duplicate samples, field blanks, equipment blanks, and trip blanks will be collected or prepared as specified in the QAA.

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Category 1

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- Verification -- Verification activities are required for the above practices, including surveillance and periodic record audits. These activities will be documented and become part of the completed project records.

6.1 QA/QC SAMPLES FOR FIELD GC ANALYSIS

Frequency of calibration, method blanks, replicates, etc. are dependent upon project Data Quality Objectives (DQOs), and must be addressed in the project-specific Quality Assurance Addendum (QAA).

7.0 DOCUMENTATION

For each soil gas location, a permanent record of the implementation of this SOP will be kept by documenting field observations and data. Observations and data will be recorded with black waterproof ink on the attached forms; the Photoionization Detector Field Data Form (Form 3.9A), the Flame Ionization Field Data Form (Form 3.9B), the Soil Gas Survey Map (form 3.9C), and the Soil Gas Survey Form (Form 3.9D). Observations may also be documented in a bound weatherproof field notebook with consecutively numbered pages. This information should include the following:

- Sampler's name (form)
- Date and time of sample collection (form)
- Sampling identification (form)
- Weather conditions (notebook)
- Sampling depth (form)

EG&G ROCKY FLATS PLANT
EMAD GEOTECHNICAL SOP

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- Driving characteristics of the soil probe (notebook)
- Description of the surface features (drainage, facilities, etc.), soils, any contamination noted, and trenches or any other feature that may impact the soil gas measurement (notebook)
- Vacuum pressure when extracting a sample (form)
- Type of sample (gas, liquid, or mixed) (form)
- Compounds and concentration of the organics measured on the GC and any replicate or blank analysis performed (form)
- All calibrations performed (form)
- Any unusual responses of the instrument (form)
- Length of time the vacuum was applied to the sample probe before a sample was taken (notebook)
- Estimated concentration and recorded retention time of all chromatographic peaks, including those that represent unknown compounds (GC chromatographs)

FACILITY CODE _____ LOG DATE _____
LOCATION ID _____ LOCATION TYPE _____
LOGGER CODE _____ FIELD REP _____

PHOTOIONIZATION DETECTOR INSTRUMENT: MODEL _____
MANUFACTURER _____ DATE/TIME CALIBRATED _____
SERIAL NO _____ ACCEPTANCE CODE _____

CALIBRATION GASES:	
TYPE/CYLINDER ID NO	CONCENTRATION (PPM)/SPAN
1	1
2	2

COMMENTS _____

[illegible]

COMPLETE BOLDING DATA FOR EVERY INFO TIME
PFD-448 (1/280)

FORM COMPLETED BY: 10/19/88

INTERNAL SECURITY - R

FLAME IONIZATION DETECTOR FIELD DATA FORM

FLAME IONIZATION DETECTOR FIELD DATA

FACILITY CODE _____ LOG DATE _____

LOCATION ID _____ LOCATION TYPE _____

LOGGER CODE _____ FIELD REP _____

FLAME IONIZATION DETECTOR INSTRUMENT :

MANUFACTURER _____ MODEL _____

SERIAL NO _____

DATE/TIME CALIBRATED _____ ACCEPTANCE CODE _____

CALIBRATION GASES :	
TYPE/CYLINDER ID NO	CONCENTRATION (PPM)
1	1
2	2

COMMENTS _____

[illegible]

ACCEPTANCE CODES: A-ACCEPTABLE R-RECOGNIZANCE U-UNACCEPTABLE N-NOT DETERMINED

LOCATION TYPES: SB - SAMPLE BOTTLE
BH - BOREHOLE SL - SURFACE LOCATION
TP - TEST PIT WL - WELL
SS - SOIL SAMPLE OT - OTHER (EXPLAIN)

OBSERVED READING:

DM - DOWNHOLE	BZ - BREATHING ZONE
MS - HEADSPACE	D - DURING DRILLING (E2)
	OT - OTHER

Rocky Flats Plant

Form 3.9C

Environmental Restoration Program

Soil Gas Survey Map

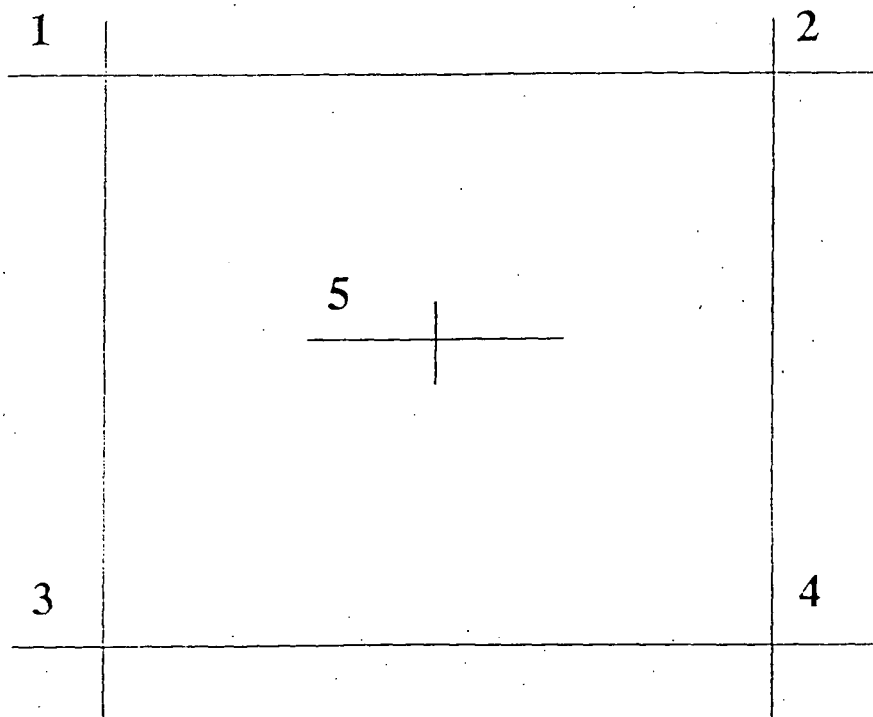
OU No: _____

SWMU No: _____

Date: _____

Sample team members: _____

GRID BLOCK



Coordinates: 1. _____ 2. _____

3. _____ 4. _____ 5. _____

6. _____ 7. _____ 8. _____

Soil Gas Survey Form

No.	Model No.	Serial No.	Cal. Factor	Background
-----	-----------	------------	-------------	------------

Date:

area:

sample ID #	Map Intersect Sample Location	TIME	Sample Depth (ft)	Field Reading 1	Field Reading 2	Comments:
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APPENDIX A
VOLATILE ORGANIC SAMPLING AND ANALYSES
IN SOIL GAS, SOILS, WATER, AND ATMOSPHERE
BY MODIFIED EPA 502.2

VOLATILE ORGANIC SAMPLING AND ANALYSES IN SOIL GAS,
SOILS, WATER, AND ATMOSPHERE BY MODIFIED EPA 502.2
HYDRO GEO CHEM, INC.

Hydro Geo Chem, Inc.
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Tucson, Arizona 85705
(602)623-6981

VOLATILE ORGANIC ANALYSES SAMPLING AND IN SOIL GAS,
SOILS, WATER, AND ATMOSPHERE BY MODIFIED EPA 502.2
HYDRO GEO CHEM, INC.

INTRODUCTION

On site analysis of volatile organic compounds VOC's is increasingly important to environmental assessments. The ability to perform real-time chemical analysis during investigations of potentially contaminated soils, water, and air allows field decisions to be made regarding the depth and areal extent of the investigation.

The applications of on-site VOC analysis include soil analysis for evaluation of subsurface spills and leaking tanks; atmospheric analysis for evaluation of VOC emissions from landfills, contaminated soils, and industrial facilities; water analysis for identification and definition of the vertical and areal extent of groundwater VOC plumes; and soil gas surveys, the sampling and analysis of VOC's in the soil atmosphere in order to determine the vertical and areal distribution of VOC's in site soils.

Because VOC's are readily transported in soils by diffusive and advective processes, soil gas surveys have proved to be a powerful technique to determine whether spills have taken place on the site, to locate these spills, and, if subsurface conditions are favorable, to find and delineate groundwater VOC plumes by the presence of VOC's in overlying soils.

The analytical requirements for real-time mobile-laboratory analysis are different than the conventional VOC analyses prescribed by EPA protocols. The laboratory productivity, that is, the number of analyses required per unit time, must be much greater for the mobile facility. Otherwise, the value of using the data to modify the investigation is diminished.

Despite the need for greater productivity, the other analytical requirements for detection limits, variety of analytes, and freedom from laboratory contamination are if anything, more stringent than those of fixed laboratory facilities.

Summary of Method

The following sampling and analytical protocol has been adapted by Hydro Geo Chem to meet these stringent requirements of on-site VOC analysis.

In summary, the analytical method consists of the recently approved EPA 502.2 protocol. Table 1 lists the compounds can be analyzed using EPA 502.2 protocol. We have modified this protocol to allow greater throughput and to minimize the potential for laboratory contamination. These modifications include temperature programming and flow changes to reduce analytical time, the use of gas rather than water-solution standards, purging of VOC bottles directly rather than using a conventional water purging apparatus (this technique has recently been independently developed and used in EPA Region 5 RI/FS studies), dynamic stripping rather than

Table 1. Compounds Detectable by Hall/PID Analysis

Benzene	trans-1,2-Dichloroethene
Bromobenzene	1,2-Dichloropropane
Bromochloromethane	1,3-Dichloropropane
Bromodichloromethane	2,2-Dichloropropane
Bromoform	1,1-Dichloropropane
Bromomethane	Ethylbenzene
n-Butylbenzene	Hexachlorobutadiene
sec-Butylbenzene	Isopropylbenzene
tert-Butylbenzene	p-Isopropyltoluene
Carbon tetrachloride	Methylene chloride
Chlorobenzene	Naphthalene
Chloroethane	n-Propylbenzene
Chloroform	Styrene
Chloromethane	1,1,1,2-Tetrachloroethane
2-Chlorotoluene	1,1,2,2-Tetrachloroethane
4-Chlorotoluene	Tetrachloroethene
Dibromochloromethane	Toluene
1,2-Dibromo-3-chloropropane	1,2,3-Trichlorobenzene
1,2-Dibromoethane	1,2,4-Trichlorobenzene
Dibromomethane	1,1,1-Trichloroethane
1,2-Dichlorobenzene	1,1,2-Trichloroethane
1,3-Dichlorobenzene	Trichloroethene
1,4-Dichlorobenzene	Trichlorofluoromethane
Dichlorodifluoromethane	1,2,3-Trichloropropane
1,1-Dichloroethane	1,2,4-Trimethylbenzene
1,2-Dichloroethane	1,3,5-Trimethylbenzene
1,1-Dichloroethene	Vinyl chloride
cis-1,2-Dichloroethene	o-Xylene
	m-Xylene
	p-Xylene

solvent extraction of soils, and splitting of the sample injection stream to allow simultaneous analysis on a separate gas chromatograph of other compounds not analyzed by the 502.2 protocol.

The sampling methods included in the protocol have been designed to allow accurate, contamination-free sampling of soils, water, atmosphere, and soil gas. These methods offer a detection limit of 0.1 $\mu\text{g}/\text{kg}$ (soil), 0.01 $\mu\text{g}/\text{l}$ (soil gas or water), 0.001 $\mu\text{g}/\text{l}$ (atmosphere) for any compounds listed in Table 1. Additional, simultaneous analysis is provided for total petroleum hydrocarbons, methane, and total chlorinated hydrocarbons. The following sections document the materials, apparatus, and procedures used.

1. SAMPLING

1.1 Scope and Application

This section covers the materials, equipment and procedures utilized by Hydro Geo Chem, Inc. for collecting soil gas, atmospheric, soil, and shallow groundwater samples in the field.

1.2 Sampling Equipment

1.2.1 Sampling Probes

Sampling probes are 7 foot sections of 1" galvanized pipe or 1" hardened steel drill pipe with Acme threads. The points are machined, high carbon steel and are left behind when the pipe is hydraulically pulled back to expose the formation to pumping. Figure 1 shows our probe design. The probes are driven to the sampling depth using one of two drive point rigs. Both rigs are mounted on 1988, Ford F-450 flat-bed duallys. One rig uses a hydraulically-activated 235 lb hammer with a 3 foot, free-fall displacement. The other rig uses a mounted hydraulic 250 ft/lb, 1,000 blow/min driver. Both rigs are capable of driving sampling pipe to a depth in excess of 35 feet under normal driving conditions. Each drive point rig is equipped with hydraulic out riggers, pipe racks and steam cleaner. The probes are removed using a hydraulically activated pulling dog. Latex gloves are worn during handling and assembling of the sampling apparatus.

1.2.2 Sampling Adaptors

Soil gas samples are collected from the probes via adaptors constructed of stainless steel pipe caps brazed to stainless steel tubing connected to an inline stainless steel bellows valve.

1.2.3 Sample Holders

When sampling is performed, this valve is connected to a stainless steel sample holder containing a glass cartridge (Supelco) filled with a three layer packing of various types of adsorptive hydrophobic carbon (see Figure 2). The soil gas is passed through these layers, the first, Carbotrap, absorbing "heavy" volatiles such as dichlorobenzene, the second, Carbopack B, the lighter volatiles such as TCE and DCE, and the third, Carbosieve III, the ultralights such methylene chloride or vinyl chloride. Because the most mobile constituent, vinyl chloride, has a breakthrough volume of 158 liters, these cartridges are rated to absorb at least 158 liters of soil gas or atmospheric gas before breakthrough of any of the priority pollutants listed in EPA method 601, 602, or 624. Table 2 shows some breakthrough volumes for the types of carbon sorbents making up the adsorption the cartridge. Thus the sampling capacity of this technique far exceeds that of syringe collection. The high capacity is necessary to meet typical client specifications.

1.2.4 The water sampling train is constructed entirely of stainless steel consisting of a 1 foot length of 3/4" well screen and seven foot lengths of 1/4 stainless steel tubing.

SAMPLE COLLECTION

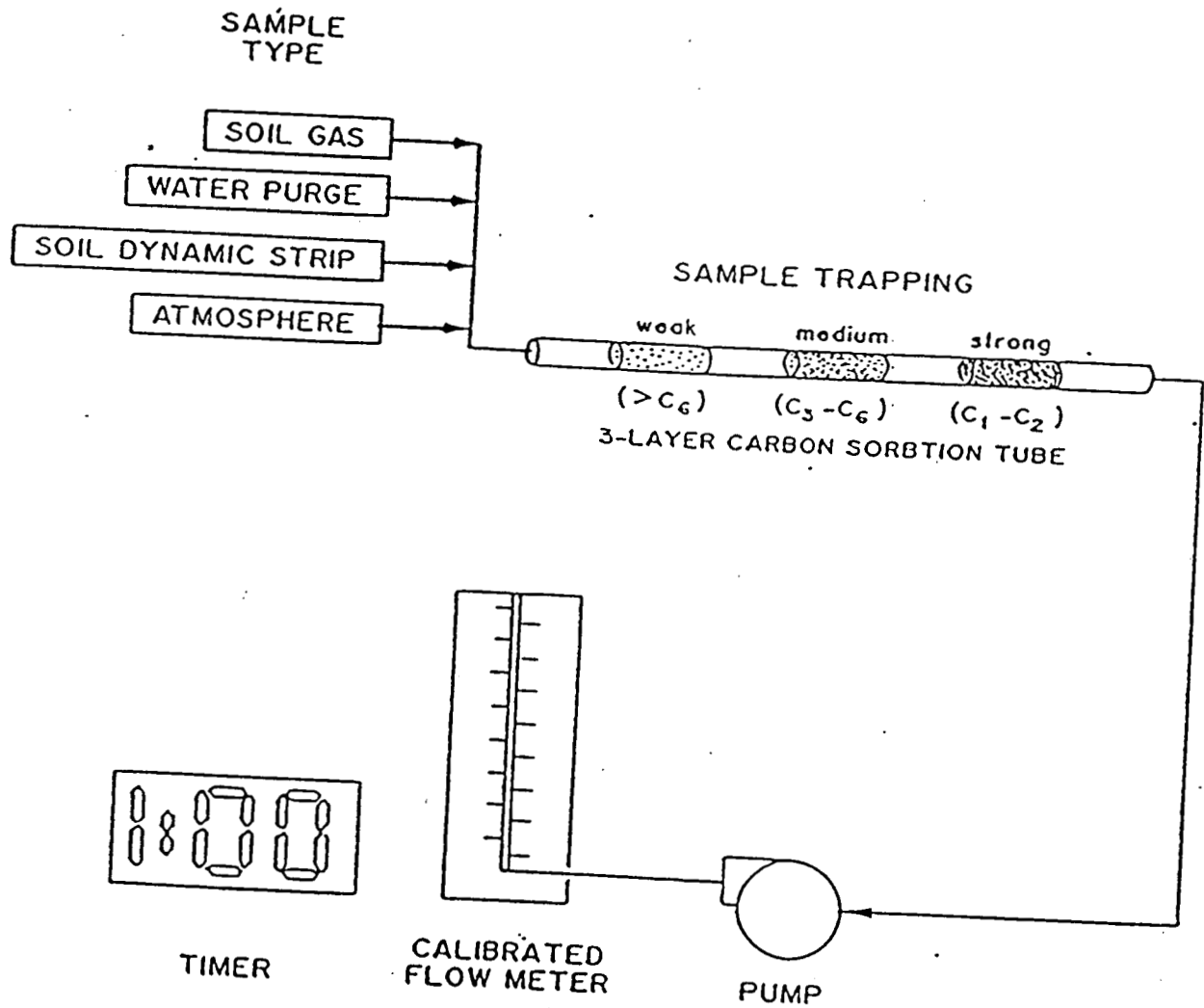


Figure 2

Table 2

Breakthrough Volumes (in Liters) for US EPA TO-1 Hydrocarbons
on the Carbosieve™ S-III/Carbopack B/Carbotrap C Thermal Desorption Tube

Hydrocarbon	Carbosieve S-III (125 mg)	Carbopack B (200 mg)	Carbotrap C (300 mg)
Vinyl Chloride	158		
Chloroform		1.1	
1,2-Dichloroethane		0.4	
1,1,1-Trichloroethane		2.7	
Carbon tetrachloride		4.7	
1,2-Dichloropropane		6.8	
Trichloroethylene		2.5	
Bromoform		1.7	
Tetrachloroethylene		2.2	
Chlorobenzene		316	
n-Heptane		262	
1-Heptene		284	
Benzene		2.3	
Toluene		130	
Ethylbenzene		4060	12.9
p-Xylene			11.2
m-xylene			11.0
o-xylene			11.0
Cumene			27.8

1.3 Sample Collection

1.3.1 Soil Gas Sampling

After purging 3 probe volumes from the system, the valve on the adaptor is shut off and the stainless steel sample cartridge housing is Swagelok-attached to a programmable mass flow controller equipped with a vacuum regulated oilless diaphragm vacuum pump. The flow controller is typically programmed to pump 200 ml of soil gas at a flow rate between 100 and 200 ml/min. When the total flow volume has been obtained, a solenoid valve is automatically closed and the sample collection is complete. The mass flow meter delivers sample volumes between 20 and 5000 standard ml with less than 2% error independent of temperature and vacuum conditions.

1.3.2 Atmospheric Sampling

Atmospheric samples are collected by positioning the probe in the area of interest, setting the pumping rate, and programming the mass flow controller. If desired, the probe can be moved through a sampling volume at a specified rate to collect an integrated sample. No purging is necessary for atmospheric samples.

1.3.3 Soil Sampling

Soil samples are collected at specified intervals using a 1.5 foot split spoon sampler with multiple brass liners. No liquids (i.e., drilling mud, water, foam) are permitted during the drilling procedure if soil samples for contaminant analyses are required. If samples are to be analyzed by the mobile laboratory, approximately 20 grams of the sample are removed from the brass sleeve using a stainless steel spatula and placed in a pre-weighed vial containing a known amount of water. All soil samples to be sent out for analysis are retained in the original brass tubes (2.5 inch diameter, 6 inches long). Immediately following removal of the brass tubes from the sampler, the center tube is first capped with aluminum foil and plastic slip caps. The slip caps are then duct taped to the brass tube to maintain a proper seal. Samples are labeled and placed in a zip lock plastic bag and stored in a cooler with dry ice.

1.3.4 Water Sampling

The water sampling train is described in Section 1.2.4. The well screen is attached to the stainless tubing and lowered into the probe. A stainless steel bottle is connected to the tubing and a Tygon line leading to the diaphragm pump is attached to the bottle. The transparent Tygon tubing is used to determine when the bottle is filled and any bubbles in the line have cleared. Excess water, which serves to purge the sampling train, is

intercepted by a vacuum flask in the Tygon line. The valve is then shut off and the bottle is disconnected from the sampling line and Tygon tubing. Opening the valve allows each of three weighed 40 ml VOC bottles to be filled to overflowing. No air bubbles are allowed to pass through the sample as the vials are filled. These are then immediately capped with a teflon-lined septum cap and stored in an inverted position at 4°C. The inverted position keeps liquid in contact with the septum, thus preventing diffusion of volatiles through the septum/glass seal. If necessary, additional 40 ml VOC bottles will be collected liquid full for outside laboratory analysis. The 40 ml VOC vials are purchased precleaned to EPA specifications from ICHM.

An alternative method used to collect water samples involves the use of 3/4" stainless steel bailers. These are lowered down the probe by a nylon cord that is replaced before each sampling.

1.4 Decontamination of Equipment

- 1.4.1 Prior to each use, each soil sampler, brass liner, and auger flight or drill stem is steam cleaned with a dilute sodium-triphosphate solution and stored on racks above ground. Care is taken with this equipment to eliminate both soil-surface and cross-hole contamination. Vinyl or latex surgical gloves are worn during handling and assembly of the sampling apparatus.

1.4.2 Probes, points, well screens, and tubing are steam cleaned prior to sampling. Adaptors and stainless steel bottles are heated to 120°C and held for 1 hour at that temperature. Carbon packed desorption cartridges are purged at 400°C with helium for 8 minutes. Cartridge holders are heated and purged at >200°C for 20 minutes.

1.4.3 Separate storage areas are provided for used and cleaned equipment. No equipment is reused without cleaning.

2. ANALYSIS

2.1 Scope

This section covers the equipment, materials, and procedures used to determine the presence and concentrations of various volatile organic compounds in the soil gas, atmospheric, soil, and shallow groundwater samples.

2.2 Detection Limits

The typical limits of detection specified are for water, soil gas, and atmospheric samples, respectively, 0.01, 0.01, and 0.001 $\mu\text{g/l}$. The applicable concentration range of this method is influenced by sample size and instrument limitations. Refer to Summary of Method for details.

2.3 Apparatus and Equipment

2.3.1 Gas Chromatographs

Hydro Geo Chem uses one of two mobile laboratories to provide on-site analyses. The first mobile laboratory is housed in a 30 foot motorized step van. The second mobile lab is contained in a 22 foot trailer. Varian 3400 and 3700 gas chromatographs are provided in our mobile laboratories (a stand-alone vehicle that operates separately from the drive point rig, thereby allowing efficient operation of both). These chromatographs are connected in parallel to an Envirochem thermal desorber (Model 850) which accepts the glass sorbtion tubes used to collect the soil gas, atmospheric, or gas purged water samples. Figure 3 is a schematic of the analytical apparatus. Helium flow is opposite to the flow direction of sample collection. The

MOBILE LABORATORY SAMPLE ANALYSIS

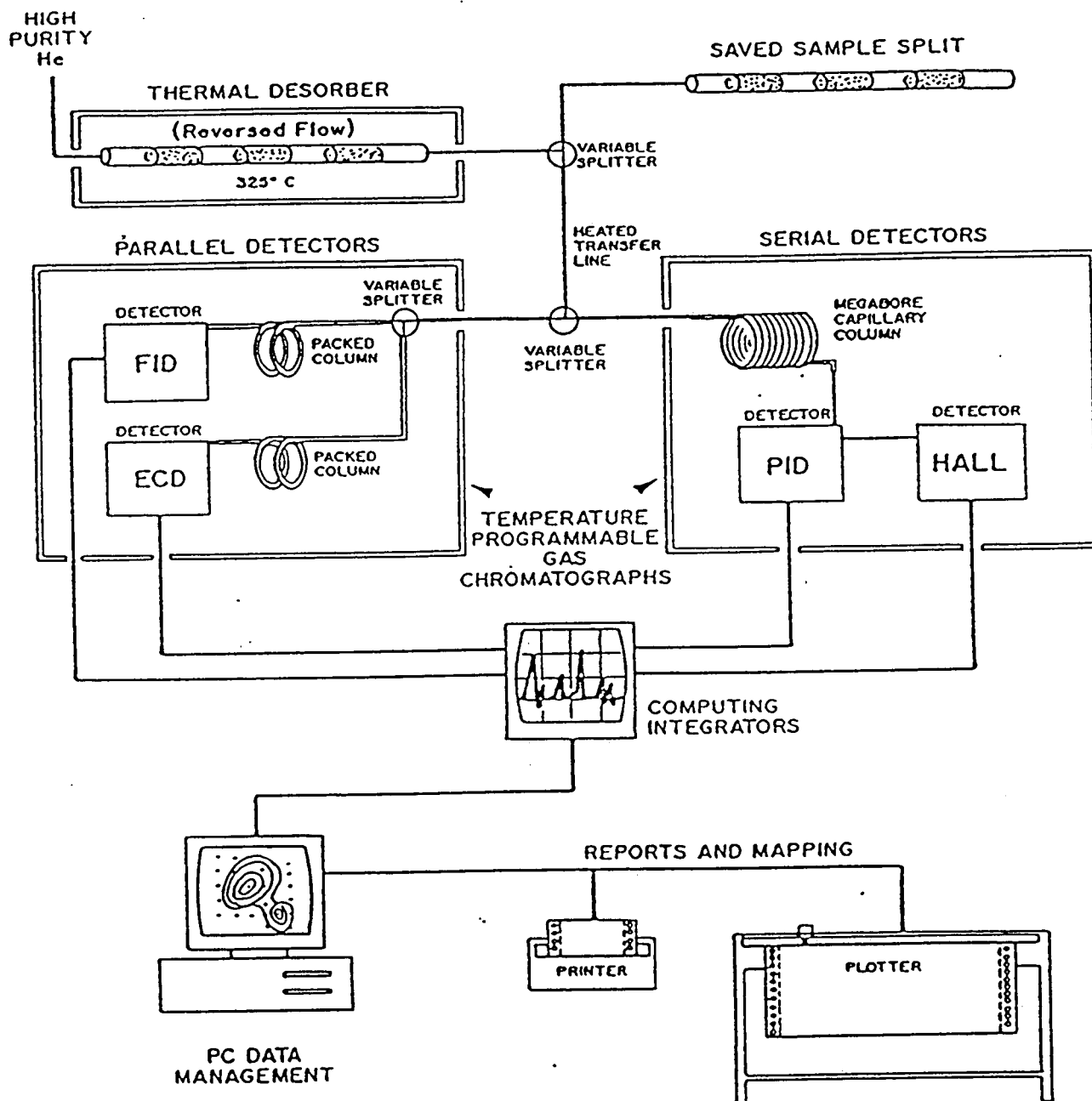


Figure 3

thermal desorber rapidly heats the sample sorbtion tube releasing the volatile organic compounds into the chromatograph by heating the tube to $380 \pm 4^{\circ}\text{C}$ in 26 ± 2 seconds. Compounds are transferred to the analytical columns via heated (250°C) nickel lines.

The Varian 3400 chromatograph is equipped with cryogenics capable of cooling the column oven to below 0°C using carbon dioxide.

The carrier gas is helium at 20 ml/minute. This gas flow is split between the transfer lines in the desorption unit by use of a flow metering valve (SGE1230400). The carrier gas flow is augmented with an additional 25 ml/minute helium before entering the photoionization detector (PID) to optimize response of both PID and Hall electrolytic conductivity (Hall) detectors.

2.3.2 GC Columns

A DB 624 Megabore column, 30m x 0.53mm (J&W Scientific) is used in the Varian 3400 chromatograph. The helium flow rate is adjusted to approximately 7.0 ml/minute at the metering valve. The temperature program varies with the client needs. A typical temperature program is as follows: the column temperature is held at 2°C for 3 minutes, then programmed to 35°C at 15 ml/minute, no hold time, to 145°C at 8 ml/minute, no hold, to 230°C at 35 ml/minute.

The 3700 GC is equipped with an OV 101 on Chromosorb W-HP 80-100, 18" x 29" packed column (Varian) used for total hydrocarbon analysis. It is also equipped with a 1/8" x 18" Carbosphere, 60/80 mesh, used to analyze for nonsorbable gases. These columns are operated isothermally at 200°C.

2.3.3 Detectors

2.3.3.1 A photoionization detector (PID) equipped with a 10.2ev lamp (Tracor Model 1703) is used.

2.3.3.2 A Hall electrolytic conductivity detector (HECD) (Tracor Model 700A) is also used. Operation conditions are as follows:

Reaction tube:	Nickel 1/16" OD
Reactor temperature:	900°C
Reactor base temperature:	250°C
Electrolyte:	n-propylalcohol
Electrolyte flow rate:	0.7 ml/min
Reaction gas:	hydrogen at 35ml/min.
Carrier gas plus make up:	helium at 32ml/min.

2.3.3.3 Hydro Geo Chem also has available in the mobile laboratory an Electron Capture Detector, ECD (Varian).

2.3.3.4 A Flame Ionization Detector, FID (Varian), is also provided.

2.3.4 Integrators

Three computing integrators are utilized depending on analysis requirements. These include PC-compatible/Nelson Analytical Chromatography software package and two computing integrators, Spectrophysics 4200, and a Varian 3400 integrator.

2.3.5 Purge and Trap Apparatus

An in-house designed and built purging apparatus (Figure 4) is used in the analysis of soil and water samples. High purity, inert (He or N₂) gas is bubbled through the sample at 200 ml/min. for 10 minutes. Purged sample components are trapped in a Supelco thermal desorption tube.

2.3.6 Standards and Reagents

2.3.6.1 Standards are prepared from stock mixtures of neat reagent grade compounds by adding a measured pipetted volume of each compound to be analyzed to the mixture and determining the weight added by difference. An aliquot volume of the final mixture is then weighed to establish density (weight/volume). Weighing is done on a 0.1 mg Mettler balance calibrated according to manufacturers guidelines with weights traceable to NBS standards. Certified mixtures of vinyl chloride in nitrogen and methane in nitrogen purchased from Matheson Gas Products, Cucamonga, California are used to standardize these compounds.

PURGE APPARATUS FOR SHALLOW WATER SAMPLES

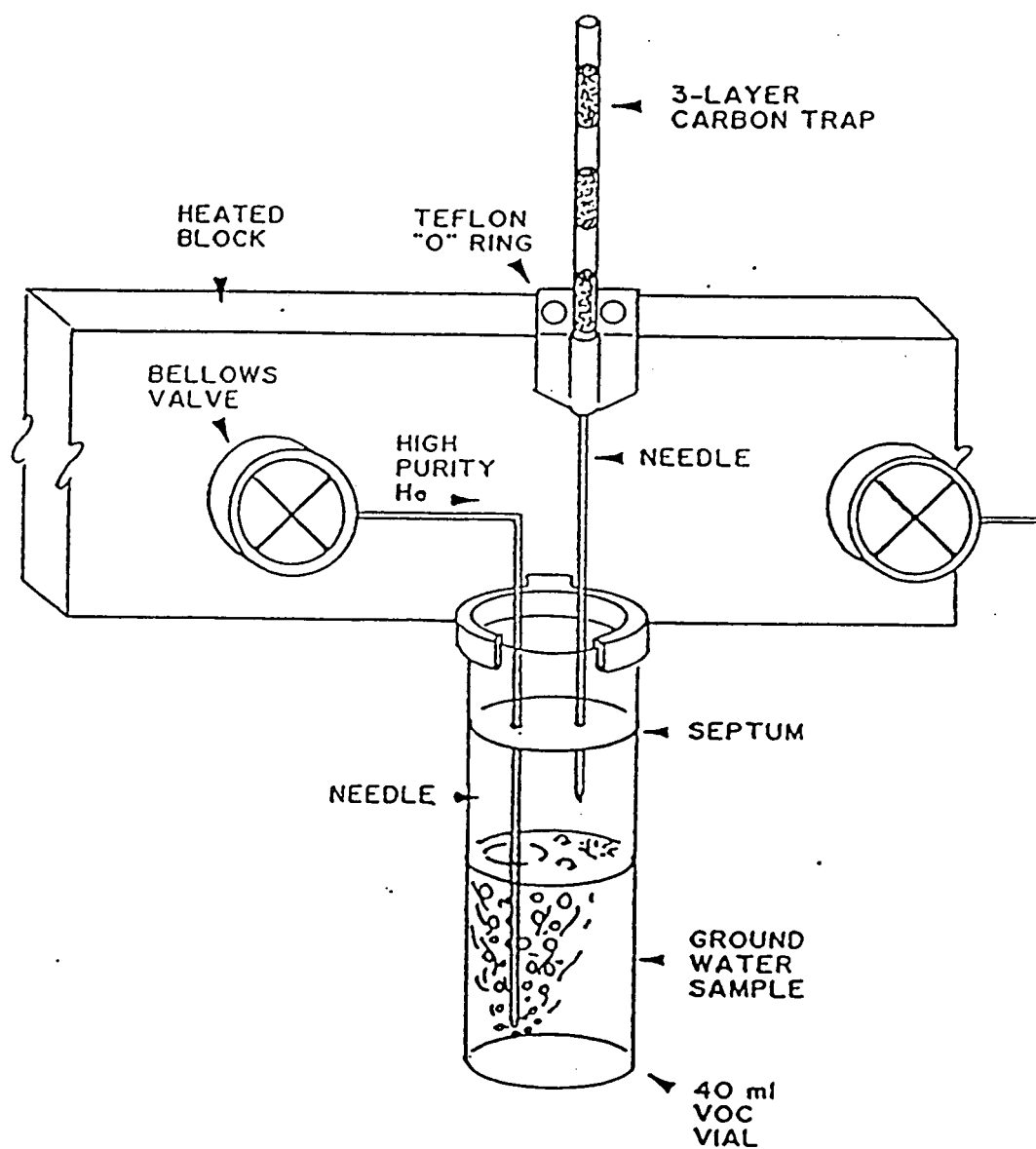


Figure 4

2.3.6.2. VOC-free water used in purging soil samples is prepared from distilled water degassed by boiling >1 hour.

2.4 Standardization and Calibration

2.4.1. Calibration

Standards for calibration are prepared as outlined in Section 2.3.6.1. A measured volume of the standard mixture is injected into a nitrogen-filled 1-liter glass, gas bottle through a septum side port. After heating the bottle to achieve volatilization and mixing of the standards, measured volumes are extracted with a gas syringe and injected into a 200 ml/min helium gas stream leading to a carbon packed sorbtion cartridge. After 2 minutes, this cartridge is inserted into the thermal desorber and analyzed exactly as the samples.

The amount of the standard stock solution injected into the gas bottle and the type of gas injection used are dependent upon the required mass of analyte. A set of calibration standards containing the method analytes and internal standard in the range of 0.05 $\mu\text{g/l}$ to 500 $\mu\text{g/l}$ based on a 200 ml soil gas sample are analyzed as outlined in Section 7 of the QAPP.

Area response versus the concentration injected of each analyte and the internal standard are tabulated. Response factors (RF) for each analyte is calculated.

Spectra Physics calculation of RF is:

$$RF = A_s(C_{is})/A_{is}(C_s)$$

where A_s = area of analyte to be measured

A_{is} = area of internal standard

C_{is} = concentration of internal standards, $\mu\text{g/l}$

C_s = concentration of analyte, $\mu\text{g/l}$

Varian 3400 calculation of RF

$$RF = C_s(A_{is})/A_s(C_{is}) \times 10,000$$

A calibration curve is prepared for each analyte. If the RF is constant (SD less than $\pm 15\%$) over the working range, the average RF is used.

New calibration curves are generated as needed or every three months.

2.4.2. Standardization

Analysis of a standard is performed at the beginning of each day. Daily standards are prepared in the same manner as the calibration standards (Section 2.3.6.1).

The amount of injected standards shall be in the range of 0.1 to 1 μg which corresponds to soil gas analysis of 200 ml samples to 0.5 to 10 $\mu\text{g}/\text{l}$, for atmospheric samples of 2000 ml, to 0.05 to 1 $\mu\text{g}/\text{l}$, and for water, to 5 to 100 $\mu\text{g}/\text{l}$. These standards shall be analyzed at least three times. If the area of any analyte varies from the response determined by the calibration curve or the average RF by greater than $\pm 20\%$, the system is recalibrated. A standard having similar detector response to that observed during analysis of field samples is run after every tenth sample. When water is to be analyzed, two water standards containing a concentration in the range of 20 $\mu\text{g}/\text{l}$ are prepared by injection of a stock standard into VOC vials half filled with VOC-free water.

2.5 Quality Control

2.5.1 System Blank

2.5.1.1 Soil Gas

A random selected sampling cartridge is analyzed daily to demonstrate that interferences from cartridges or the analytical system are under control. If interference is found at unacceptable levels, an unpacked cartridge is analyzed to determine if the interference is due to the cartridge or to the

analytical system. Appropriate measures are taken to eliminate such interferences.

2.5.1.2. Water

At the beginning of each day, the chemist fills a sampling container with reagent water and proceeds to handle it as an actual sample is handled in order to demonstrate that the system and water are interference-free. If VOC's are detected, appropriate measures will be taken to correct the problem.

2.5.1.3. Soil

System blanks are unable to be performed on soil because interference-free soil is not available and the procedure is not feasible.

2.5.2 Field Blanks

2.5.2.1 Soil Gas

Prior to each day's soil gas or atmospheric sampling, field blanks of the entire sampling apparatus are taken and analyzed to check background contamination in the sampling system and cartridges. Sampling cartridges are attached to both the inlet and outlet end of a sampling probe. The sample collected in the discharge end cartridge is representative of sampling train

contamination only while the intake cartridge provides a measure of the atmospheric concentrations. Additional field blanks are collected prior to any reuse of recleaned sampling equipment.

2.5.2.2. Water

A sampling container will be filled with interference-free water in the field in the same manner as water samples are collected. This sample, now designated as a field blank, is returned to the laboratory for analysis. If VOC's are detected, sample collection procedure will be reviewed. If necessary, sampling equipment will be thoroughly decontaminated.

2.5.2.3. Soil

Collection of field blank soil samples is not feasible due to the nature of the matrix and because interference-free soil is not available.

2.5.3 Duplicate Samples

Duplicate soil gas, atmospheric, or shallow groundwater samples are collected from each sampling location. Duplicate analyses are performed on at least 10% of the samples collected, or if the initial analysis is outside QA specifications. Duplicate analyses are not performed on soil samples because it would require homogenization of the sample, tend to release

volatiles from the sample, and therefore, limit the accuracy of the results.

2.5.4 Trip Blanks

2.5.4.1. Soil Gas

An unused sample cartridge is transported into the field with the sampling equipment. The trip blank cartridge is handled in the same manner as a sample, but a sample is not collected through this cartridge. The trip blank is returned to the lab with the other samples and analyzed. If VOC's are detected, sample handling and transport procedures are subsequently reviewed. If no VOC's are detected, this cartridge is also used as a system blank.

2.5.4.2. Water

A sampling container is filled with water determined to be interference-free and taken into the field. The trip blank container is handled in the same manner as other water samples but is not used to collect an actual sample. The trip blank is then returned to the laboratory for analysis with the other samples. If VOC's are detected, sample handling and transport procedures are reviewed and sampling equipment is decontaminated as necessary.

2.5.4.3. Soil

Trip blanks for soil sampling are not used because uncontaminated soils without background levels of organics are not available and the trip blank procedures are not feasible.

2.5.5. Matrix Spike Duplicate

2.5.5.1. Soil Gas

The standard calibration procedure for soil gas analysis, the matrix being the activated carbon in the sample collection cartridges only, accounts for matrix spike duplicates.

2.5.5.2. Water

Once per day a duplicate field sample is with a calibration standard of known concentration. This spiked sample is then processed and analyzed in the same manner as all samples. The difference between the reported concentration per compound and the concentration of the spike are then compared to the previous analysis of the unspiked sample duplicate.

2.5.5.3. Soil

Because a spike cannot be effectively and uniformly distributed throughout a soil sample, matrix spike duplicates are unreliable indicators and therefore not collected.

2.5.6 Chromatographic Information

On the first page of each day's chromatograms, the following system parameters are noted:

- A) Gas flows for H₂, N₂, and air
- B) Tank pressures for H₂, N₂, and air
- C) Temperatures
 - 1. Injector
 - 2. Columns
 - 3. Detector
 - 4. Thermal desorber oven
 - 5. Thermal desorber transfer lines
 - 6. Thermal desorber desorption temperature and duration
- D) Integrator parameters
 - 1. Attenuation
 - 2. Peak markers
 - 3. Baseline offset
- E) Column(s)
 - 1. Type
 - 2. Length and diameter
 - 3. Packing material
 - 4. Temperature
- F) Operator
- G) Date

If any system parameters change, the chromatograms shall be stamped and changes noted.

2.5.7 Internal Quality Control

All chromatograms are reviewed internally by a chemist other than the chemist performing the analysis.

2.5.8 Outside Quality Control Audits

Samples are sent to independent laboratories for analysis periodically as a quality assurance check.

2.5.9 Sample Chain of Custody

All samples are labeled with the following information:

- 1) Sample identification number
- 2) Date and time of sample collection
- 3) Name of sampler

In addition to labeling the samples, a field data/chain of custody form is completed in duplicate for each sample (Figure 5). At the time of sample collection, the field sampler signs the custody form and records the date, time and other pertinent information. The sample is then transferred to the laboratory, where the individual receiving the sample for analysis signs the original custody form and records the date and time. This Soil Gas Field

Figure 5

HYDRO GEO CHEM, INC. SAMPLE INFORMATION AND TRANSFER FORM
 -- Original to Mobile Lab -- Copy Kept in Field Notebook

Location #: _____ Sample #: _____ Data Base File: _____

Location Description: _____

Sampler (Signature): _____ Soil? ___ Water? ___ Soil Gas? ___ Atmospheric? ___

Weather: _____ Barometric Pressure: _____

Wind Direction/Speed: _____ Air Temp (°F): _____

Surface Conditions: _____ Soil Temp (°F): _____

Time/Date: _____ Cartridge(s) #: _____

Probe Depth: _____ Probe #: _____ Probe Volume: _____

Adapter #: _____ Cylinder #: _____ Vacuum Gage Reading: _____

Sample Size: _____ Pump Flow Rate & Duration: _____

Purge Flow Rate & Duration: _____ Notes: _____

Lab Receipt: (Signature): _____ Time/Date: _____

Compound Analyzed	Measured Concentration (µg/l)		Chromatogram #
	1st	2nd	
DCM			
Chloroform			
CCl ₄			
VCl			
1,1 DCE			
trans-1,2 DCE			
cis-1,2 DCE			
TCE			
PCE			
1,1 DCA			
1,2 DCA			
1,1,1 TCA			
Benzene			
Toluene			
Ethylbenzene			
Xylenes			

Data Sheet (Chain of Custody Form) is then filed in a notebook with the hard copy of the analytical results and eventually becomes part of the the final evidence file. The copy is retained in the field notebook.

2.6 Procedures

2.6.1 Typical chromatographic equations are summarized in Section 2.7.

2.6.2 The system is calibrated daily as described in Section 2.4.1.

2.6.3 Water Samples

Approximately half of the water sample is disposed of and the vial resealed. This sample is weighed to determine volume and purged with 200 ml/min N_2 for 10 minutes. The purged volatile compounds are trapped on a carbon packed desorption cartridge.

2.6.4 Soil Samples

Soil samples collected for in-house analysis are placed in a water bath (90°C) after being well agitated. These samples are purged in the same manner as water samples. The samples are weighed before purging to determine sample mass.

2.6.5 Gas Samples

The thermal desorption tubes on which the samples are collected are placed in the thermal desorber and heated to $380 \pm 4^{\circ}\text{C}$ with a helium flow of 20 ml/min. at the same time that the GC temperature program is initiated and data acquisition started. The trapped materials are desorbed and carried through the heated transfer lines to the GC columns where separation occurs (Figure 3).

2.7 Calculations

2.7.1 Each analyte in the sample chromatogram is identified by comparing the retention time of the suspect peak to retention times generated by the calibration standards on the appropriate detector. When applicable, the relative response of the alternate detector to the analyte is determined. The relative response should agree to within 20% of the relative response determined from the standards.

2.7.2 Quantitation is usually performed on the detector which exhibits the greater response if both detectors respond to an analyte. In cases where greater specificity or precision would result, the analyst uses his/her professional judgement in determining the alternate detector.

2.7.3 The concentration of the unknowns is determined by using the calibration curve or by comparing the peak height or area of the unknowns to the peak height or area of the standards as follows:

$$C_u = A_u/A_{is} \times C_{is}/RF$$

where C_u = concentration of the analyte in sample in $\mu\text{g/l}$

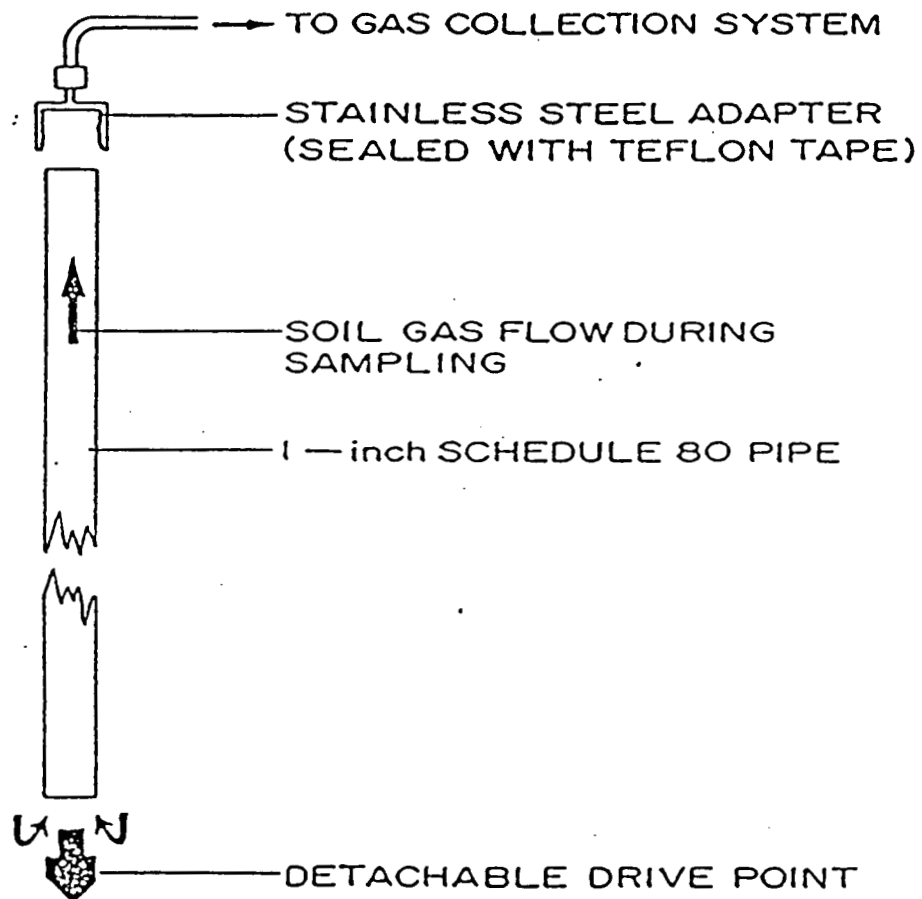
C_{is} = concentration of the internal standard in $\mu\text{g/l}$

A_u = peak area of the analyte

A_{is} = peak area of the internal standard

RF = relative response factor

2.7.4 The results for the unknown samples are reported in $\mu\text{g/l}$.
The results are rounded off to the nearest 0.01 $\mu\text{g/l}$ or 2 significant figures.



SOIL GAS SAMPLING PROBE

Figure 1

EG&G ROCKY FLATS PLANT
EMAD GEOTECHNICAL SOP

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TITLE:
BOREHOLE CLEARING

Approved By:

J. W. Langman

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for clearing drill sites and intrusive work sites within Individual Hazardous Substance Sites (IHSSs). Geophysical clearing will be implemented to ensure that selected locations are free of buried metal objects to a depth of 18 feet and metal utility lines. This SOP describes geophysical, administrative clearance techniques, and geophysical data reduction and analyses that will be used for field data collection and documentation.

The geophysical techniques that are employed involve electromagnetic (EM) techniques and a magnetic locator. EM and magnetic surveys can be used for identifying areas where subsurface metal objects might be located. The techniques indicate contrasts in conditions due to variations in the electrical conductivity or magnetic properties of subsurface materials.

A magnetic locator can be used when the clearing depth-of-interest is 18 inches or less. EM techniques and a magnetic locator will both be used when the clearing depth-of-interest is deeper than 18 inches.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Oversight and supervision of the geophysical surveys will be conducted by a trained senior level geophysicist. Project staff performing these surveys will be trained geophysicists or trained personnel with a significant amount of geophysical field experience. The senior geophysicists should approve the assisting project staff. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

The subcontractor's project manager is responsible for obtaining administrative borehole clearance.

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4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. October 1988.

RCRA Facility Investigation Guidance. EPA. Interim Final. May 1989.

5.0 GEOPHYSICAL EQUIPMENT AND PROCEDURES

5.1 INTRODUCTION

Borehole clearing, using geophysical methods, will be employed within an IHSS where buried trenches are known to exist or where buried metal may be present. Surface geophysical surveys have been conducted at the RFP. Research of these previous geophysical surveys should be exhausted prior to conducting the following procedures.

Instruments used for geophysical clearing will be recalibrated and recertified, if required. The date of the manufacturer's last calibration and certification will be documented on the Borehole Clearing Analysis Form (Form 3.10A).

Each instrument will have a field calibration check prior to and after field use. Personnel performing the field calibration check should refer to the manufacturer's instructions. An example

of a field calibration check would be to use the instrument over a known buried object. If the instrument does not respond appropriately, the instrument should be returned to the manufacturer for recalibration and recertification.

Geophysical methods have limitations which must be considered when implementing a geophysical survey. In some instances, the limitations may be sufficient to make the geophysical results ambiguous or non-conclusive. Therefore, it is imperative that an experienced geophysical operator conduct the clearing of boreholes.

Both electromagnetics and magnetics are influenced by surface cultural features, such as fences, power lines, and metallic debris. These cultural effects can be mitigated by the use of a directional magnetic locator, which responds to a magnetic gradient. However, if borehole clearing is being performed within 40 to 50 feet of a cultural feature, reliable geophysical clearing may be difficult to achieve. In cases where a site cannot be definitively cleared, the location should be moved to the nearest clearable location.

5.2 ELECTROMAGNETICS

An EM survey can be used to detect ferrous and nonferrous metals as well as areas of high inorganic contamination. This method involves the induction of electrical current into the ground. A small alternating current passing through a transmitter coil produces a primary magnetic field. Through inductive coupling, the primary magnetic field produces small eddy currents in the subsurface which, in turn, create their own secondary magnetic field. The receiver coil senses both the primary and secondary fields. This results in an output voltage that is linearly related to the terrain conductivity. The instrument then converts the voltage to a ground conductivity value which can be recorded by a strip recorder or digital logger. Electrical conductivity is a function of the soil or rock type, the porosity and permeability of the rock units, and the fluids and fluid constituents

filling the pore space. The conductivity values are subsequently plotted on a map so that their variation over the site can be analyzed.

A Geonics EM-31, or equivalent ground conductivity meter will be used for the EM surveys. Through the use of the horizontal dipole mode (HDM), the unit has a depth penetration to 9 feet. By monitoring the in-phase component of the induced magnetic field, small amounts of subsurface metal can be detected. When deeper penetration is required, the vertical dipole mode (VDM) will be used in addition to the HDM. This scenario will provide high resolution detection of objects to 9 feet and will allow detection of larger metal objects to 18 feet. The size of a metal object that can be detected is proportional to the depth of burial. For shallow investigation (less than 9 feet), the HDM provides the greatest resolution and can normally detect objects as small as a 1-foot length of rebar. Table 3.10-1 summarizes instrument modes and applications.

Table 3.10-1
EM-31 INSTRUMENT MODE APPLICATION

<u>Mode</u>	<u>Depth of Penetration (ft)</u>	<u>Approximate Size of Detected Object</u>
HDM	9	1-foot piece of rebar
VDM	18	Steel drum

5.2.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete the EM survey:

- A Geonics EM-31, EM-34-3, or equivalent terrain conductivity meter

- Digital logger and/or analog strip recorder (when data collection is over large grid area)
- Appropriate health and safety equipment
- Wood stakes or lath
- Flagging
- Field notebook
- Pens with nonwater-soluble ink
- Form 3.10A, Borehole Clearing Analysis (see Section 7.0, Documentation).

5.2.2 Field Procedure

A standard field procedure for conducting an EM survey is initiated by a reconnaissance survey of each drill site. The survey will involve a review of existing magnetic data at the site, a review of the site utility plans, an acknowledgement from the telephone and utility site locators that the site is clear of these utilities, and a field check for overhead wires, pipes, or other objects that may restrict drilling operations. Note surface conditions of site on Form 3.10A (see Section 7.0, Documentation) including excessive and/or large metal objects on the ground surface and large variations in topography. Following the instrument manufacturer's instructions, initiate site survey traverse on an approximate 1-foot grid, clearing a minimum of 6 feet around the drilling location stake. When anomalous values indicative of buried metal are observed, record the anomaly on Form 3.10A. If an anomaly is not present, document results on Form 3.10A.

Drilling locations with anomalous values will require moving the location to the nearest "clear" area. By using the above procedures, determine an area within 50 feet of the original drilling location that is free of anomalies. Mark the new drilling location with a wood stake and document new location on Form 3.10A. Notify the project site manager of the new location.

For larger areas or for locating buried trenches or pits, follow a surveyed grid pattern when traversing with the EM instrument. If the grid is not surveyed prior to the EM traverse, place a wood stake marker at the end of each traverse and document the marker location on the field data record (Form 3.10A). All EM traverses should be documented on a field map during the survey. For larger areas, a portable computer may be required to quickly analyze the data and facilitate the location of additional survey lines.

5.3 MAGNETIC LOCATOR

A magnetic locator detects magnetic fields associated with certain objects. The depth of investigation depends on the size of the object. The Schonstedt magnetic locator, for example, can detect well casings up to 15 feet deep; however, a 1 1/4-inch nail can be detected only to a depth of 8 inches.

A magnetic locator responds to the magnetic gradient between two magnetic field sensors (A and B). If no anomalies exist, the magnetic field between sensors A and B is balanced, and a 40 Hz frequency signal is heard on the magnetic locator's audio output. This frequency output (40 Hz) is the ambient magnetic field of the earth. However, when the magnetic field becomes stronger at sensor A (located at the bottom of the locator) than at sensor B, the output signal increases in frequency. When the tip of the locator is directly over the ferrous object, the audio signal increases to its highest frequency.

5.3.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete the geophysical survey:

- Schonstedt Model GA-52B magnetic locator or equivalent
- Appropriate health and safety equipment

- Wood stakes or lath
- Flagging
- Field notebook
- Pens
- Form 3.10A, Borehole Clearing Analysis (see Section 7.0, Documentation)

5.3.2 Field Procedure

The field procedures for a magnetic survey are the same as the procedures described for the EM survey (Subsection 5.2.2).

5.4 DATA REDUCTION AND ANALYSIS

When the anticipated hazards are isolated pieces of metal, borehole locations will be cleared to a minimum of 6 feet around the drilling location stake. In these cases, data will not be retained for later analysis, but the results will be documented on Form 3.10A. If an anomalous area within 6 feet of the borehole location stake is identified, the borehole location will be changed to an anomaly-free area within 50 feet of the original borehole location to minimize the possibility of contact with any anomalous material below the surface.

When the hazard is buried trenches or pits, larger areas will have to be geophysically surveyed to clear borehole locations. In these cases, electromagnetic data will be collected with a digital data logger. The data will be transferred to a personal computer for analysis. Adjustments to the boring location (if required) will be made after the data are analyzed and interpreted.

In both of the above cases, Form 3.10A will be used to document the procedures and reasoning for the relocation or approval of a borehole location.

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At all times, geophysical data will be collected and interpreted in a conservative and prudent manner. Additionally, appropriate levels of caution will be exercised by all field crews involved in intrusive activities, even on geophysically "cleared" boring locations.

6.0 ADMINISTRATIVE BOREHOLE CLEARANCE

Administrative borehole clearance will be required for drilling operations at the RFP and will consist of obtaining work and excavation permits. Copies of these forms are included in Section 7.0, Documentation.

6.1 RADIOLOGICAL/HEALTH & SAFETY WORK PERMIT

Work permits will be required for drilling operations in all restricted access areas, which include IHSSs. These permits will be issued by the EG&G construction manager and will be valid for one week of drilling operations (see Section 7.0, Documentation). If field operations extend beyond a week's time, a request for an additional work permit will be submitted to the construction manager. This request will include details of the drilling operations planned for the following week.

Daily work permits will be required for all drilling operations within the perimeter security zone (PSZ).

The permitting process will consist of the construction manager reviewing the field operations plan (FOP), EG&G personnel clearing underground utilities, and screening for low energy radiation.

The work permit will be kept at the drill site during the drilling operation.

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Instructions and requirements for the use of a Radiological/Health & Safety Work Permit (see Section 7.0, Documentation) are contained in H&S 6.05 Radiological/H&S Work Permit available through EG&G.

6.2 EXCAVATION PERMIT

Excavation permits will be required for drilling or excavating deeper than 18 inches. These permits will also be issued by the EG&G construction manager. A permit will be required for each project and will be valid for 60 days. The excavation permit will also be kept at the drill site.

7.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting field observations and data. The date of the manufacturer's most recent calibration and certification will be documented if this information is available. Field calibration checks, geophysical observations, and data will be documented on the Borehole Clearing Analysis Form (Form 3.10A). Administrative clearances will be documented on the Radiological/Health and Safety Work Permit, and the Rocky Flats Excavation Permit.

BOREHOLE CLEARING ANALYSIS

Project Name: _____ Date: _____

Project Number: _____ Operator: _____

Survey Type: _____ Instrumentation: _____

Date of last calibration and instrument certification: _____

Field calibration dates: _____

Location (Borehole ID and Coordinates (if Available))	Surface Condition	Max Depth of Interest	Anomaly Present (Y/N)	Comments or Action

RADIOLOGICAL/HEALTH & SAFETY WORK PERMIT

Instructions and requirements for the use of this form are contained in H&S 6.05 Radiological/H&S Work Permit

SECTION I - JOB INFORMATION (To be completed by job supervisor or permit initiator)

Job Name _____ Auth or WO # _____
Bldg. _____ Room # _____ Date _____ From _____ (AM/PM) To _____ (AM/PM)
Scope of Work _____

SECTION II - DESCRIPTION OF HAZARDS (To be completed by responsible user)

MATERIAL HAZARDS

____ HNO₃ (Nitric Acid)
____ HCl (Hydrochloric Acid)
____ H₂SO₄ (Sulfuric Acid)
____ HF (Hydrofluoric Acid)
____ Caustic
____ Flammables
____ Trichloroethylene
____ Beryllium
____ Plutonium
____ Uranium
____ Asbestos

ELECTRICAL HAZARDS

Energized System?
____ Yes ____ No
____ 120V
____ 220V
____ 480V
____ 600V
____ Above 600V
____ V
____ involved?
____ involved?

HIGH TEMP/HIGH PRESSURE

____ Vacuum
____ Ambient Pressure
____ <15 psig
____ >15 psig
____ psig
____ Below Ambient Temp
____ °F
____ Ambient Temp
____ Above Ambient Temp
____ °F
____ Steam System
____ Hydraulic System

Fire Suppression Interruption? ____ Yes ____ No

Other hazards and precautions _____

SAMPLE: MULTIPLE COPIES

SECTION III - RADIOLOGICAL AND NONRADIOLOGICAL SAFETY REQUIREMENTS (To be completed by Radiology, Protection, and/or H&S Area Engineer).

JSA REQUIRED ____ Yes ____ No

JOBSITE REVIEW REQUIRED ____ Yes ____ No

'A' PACKAGE REQUIRED ____ Yes ____ No

RADIOLOGICAL PROTECTION TECHNOLOGIST (RPT) REQUIRED ____ YES ____ NO

PROTECTIVE APPAREL

____ Coveralls
____ Tyvek Suit
____ Plastic Suit
____ Acid Suit
____ Surgeon's Gloves
____ Plastic Gloves
____ Rubber Gloves
____ Leather Gloves
____ Cloth Cap
____ Cloth Hood
____ Plastic Hood
____ Booties
____ Plastic Booties
____ Rubber Boots
____ Safety Glasses
____ Goggles
____ Face Shield
____ Hard Hat
____ Hearing Protection
____ Taped Openings
____ Other _____

RESPIRATORY REQUIREMENTS

____ Half Mask
____ Full Face
____ Supplied Breathing Air
____ SCBA
____ Chemical Canister

RADIOLOGICAL PROTECTION REQUIREMENTS

____ Start of job
____ On call
____ Full time

DOSIMETRY REQUIREMENTS

____ TLD Dosimeter
____ Extremity Dosimeter
____ Special Dosimeter

ELECTRICAL PROTECTION REQUIREMENTS

(Consult Job Supervisor)

____ Insulating Mat
____ Insulating Blanket
____ Cover up
____ High Voltage Sleeves
____ High Voltage Gloves
____ Class I
____ Class II
____ Hot Sticks
____ TIC Tracer
____ Insulated Bucket Truck
____ Grounding Cable
____ Grounding Stick

CONTAMINATION CONTROL VENTILATION REQUIREMENTS

____ Containment Pen
____ Plastic House
____ SBA House
____ Plastic Sleeve
____ Glove Bag
____ Air Mover
____ Down Draft
____ GB Exhaust
____ Other _____

RADIOLOGICAL PROTECTION PRE-JOB SURVEY

Contamination levels and extent _____

Gamma _____

Neutron _____

Limitations _____

RPT Signature _____

RADIOLOGICAL PROTECTION POST-JOB SURVEY

Contamination levels and extent _____

Gamma _____

Neutron _____

RPT Signature _____

Other Special Requirements _____

RADIOLOGICAL/HEALTH & SAFETY WORK PERMIT - CONTINUED

Auth or WO # _____ Date _____

SECTION IV - PREPARATION FOR THE JOB (To be completed by the responsible user and job supervisor)

The area or equipment is ready to be worked on and is in safe condition	_____ Yes	_____ N/A
The necessary systems have been shutdown, drained, blanked, etc.	_____ Yes	_____ N/A
The necessary systems have been locked out/tagged out. # _____	_____ Yes	_____ N/A
Voltage checked after lock out.	_____ Yes	_____ N/A
Utilities has been notified of upcoming work and is prepared.	_____ Yes	_____ N/A
The Fire Department has been notified of upcoming work and is prepared.	_____ Yes	_____ N/A

SECTION V - APPROVAL SIGNATURES

THE ABOVE REQUIREMENTS HAVE BEEN REVIEWED WITH AND ARE UNDERSTOOD BY ALL JOB PERSONNEL.

(Job personnel signatures)

The Building Manager (or designee) has been notified of upcoming work _____
(notifier's initials)

THE SIGNATURES BELOW INDICATE REVIEW AND CONCURRENCE WITH THE WORK PERMIT

Responsible User _____

Supervisor _____

RPT Foreman (if applicable) _____

Contractor Supervisor (if applicable) _____

H&S Area Engineer _____

Other _____

SAMPLE: MULTIPLE COPIES

SECTION VI - PERMIT EXTENSION

WORK PERMIT EXTENDED TO: _____

H&S Area Engineer _____

Job Supervisor agrees to tour area daily to ensure compliance with H&S requirements. (Initials required for each day of extension)

Dates: _____

Initials: _____

DISTRIBUTION

Job Supervisor -	White (retain permanently with job file)
Responsible User -	Blue (retain for 30 days)
Radiological Protection -	Yellow (retain for 30 days)
H&S Area Engineer -	Buff (info copy)

POST CARD AT JOB SITE

ROCKY FLATS EXCAVATION PERMIT

ATTACHMENT CMIC-15a

12/13/1988

LOCATION/PROJECT TITLE/WORK DESCRIPTION: _____

CONTRACTOR: _____ CONTRACT DWG/SHEET NO: _____

AUTHORIZATION NO: _____ PERMIT NO: _____ DRAWING NO: _____

CAUTIONS/OBSTRUCTIONS/SPECIAL INSTRUCTIONS: _____

SAMPLE: MULTIPLE COPIES

LOCATOR TAPE ISSUED: _____ PERMIT LIMITS (DURATION/BOUNDARY): _____

RADIATION MONITORING SURVEY/RESULTS: _____

APPROVALS

RCRA: _____

FE (PCSE)	PLANT POWER	UTILITIES	ALARMS SUP.	TELECOM	COMM SUP.	PLANT PROTECTION

FIRE DEPT.	ENVIRONMENTAL	LIQUID WASTE	IND. SAFETY	BLDG. SUPERINTENDENT	INDUSTRIAL HYGIENE	HSE AREA ENGR/ SHIFT SUPER

RESPONSIBLE JOB SUPERVISOR: _____

OPERATOR: _____

EXCAVATION COORDINATOR: _____ DATE: _____

INITIAL INSPECTION

BY: _____

DATE: _____

DAILY

INITIALS: _____

DATE: _____

NOTES:

ATTACH DRAWING/SKETCH
SEE REVERSE SIDE FOR ADDITIONAL
INSTRUCTIONS

DISTRIBUTION:

WHITE: C.M.I.C. FILE
BLUE: FE (PCSE)
YELLOW: HS&E
CARD: JOB SITE

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TITLE:
PLUGGING AND ABANDONMENT
OF WELLS

Approved By:

J.W. Langman

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at Rocky Flats to plug and abandon (P&A) wells. Plugging refers to the physical process of filling the well cavity with grout while abandonment refers to the completion and documentation of all requirements of this SOP. Abandonment involves plugging the well with grout, and all related activities and documentation as described in this SOP. A well is defined for the purpose of this SOP as a ground penetration intended for monitoring the chemical, physical or potentiometric properties of groundwater, a ground penetration intended for production of groundwater, or a ground penetration of unknown status. Abandonment of boreholes, which are defined as ground penetrations drilled primarily for obtaining geologic and environmental information, is addressed in SOP 3.5, Plugging and Abandonment of Boreholes.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the abandonment of wells will be geologists, geotechnical engineers or field technicians with an appropriate amount of applicable field experience or on-the-job training under supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Nielsen, and J.E. Denne. 1989. "Handbook of Suggested Practices for the Design and Installation of Ground Water Monitoring Wells," EPA 600/4-89/034. National Water Well Association. 398 pp.

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Colorado Division of Water Resources, Board of Examiners of Water Well Construction and Pump Installation Contractors. 1988. "Revised and Amended Rules and Regulations of the Board of Examiners of Water Well Construction and Pump Installation Contractors," 29 pp.

U.S. Environmental Protection Agency. "RCRA Ground Water Monitoring Technical Enforcement Guidance Document," 1986. Office of Solid Waste and Emergency Response. OSWER-9950.1. 317 pp.

U.S. Environmental Protection Agency. 1975. Manual of Water Well Construction Practices; Office of Water Supply. EPA-570/9-75-001. 156 pp.

4.2

INTERNAL REFERENCES

Related SOPs that are cross-referenced by this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 1.4, Heavy Equipment Decontamination
- SOP 1.6, Handling of Personal Protective Equipment
- SOP 1.7, Handling of Decontamination Water and Wash Water
- SOP 1.8, Handling of Drilling Fluids and Cuttings
- SOP 1.10, Receiving, Labeling, and Handling Waste Containers
- SOP 1.11, Field Communications
- SOP 1.12, Rocky Flats Plant Access and Control
- SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP 3.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP 3.4, Rotary Drilling and Rock Coring
- SOP 3.5, Plugging and Abandonment of Boreholes
- SOP 3.10, Borehole Clearing

5.0 EQUIPMENT AND PROCEDURES

Several field activities will be conducted in the process of well abandonment that are addressed in other SOPs, primarily within categories 1.0 -- Field Operations and 3.0 -- Geotechnical.

5.1 MATERIALS AND EQUIPMENT

The following materials and equipment may be used:

- Health and safety monitoring equipment and personal protective equipment according to the Health and Safety Plan.
- Well plugging and abandonment form.
- Drill rig and associated equipment.
- Reduced pH bentonite grout (American Colloid "Pure Gold", or approved equivalent), mixed in a powered mechanical grout mixer according to manufacturer's recommendations. The grout will contain at least 30 percent solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. A mud balance will be used to check grout density prior to pumping for each borehole.
- Concrete.
- Portable metal tanks for concrete flushing and mixing.
- High pressure steamer/spray.

- Phosphate-free, lab grade detergent (e.g., Liquinox).
- Drums for containment of borehole effluent and sediment.
- Weighted measuring tape.
- Mirror.
- Spotlight.

5.2

PROCEDURES

Equipment for plugging and abandoning boreholes will be used according to the pertinent requirements of SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques and SOP 3.4, Rotary Drilling and Rock Coring. These requirements include use of contaminant-free lubricants only, and visual monitoring of equipment for hydraulic and/or fuel or oil leaks. All procedures will be conducted according to the Site Health and Safety Program Plan. If necessary, project-specific requirements will be addressed in a Standard Operating Procedure Addendum (SOPA).

Several methods of well abandonment are addressed in the following sections. Selection of the appropriate method of abandonment for a given well must be addressed in the project-specific work plan, based on information compiled for the well. Factors to be considered in selecting the abandonment method include:

- Casing material
- Casing condition
- Diameter of casing and borehole

- Type and quality of original seal
- Depth of the well
- Plumbness of the well
- Hydrogeologic setting
- Location and type of zone(s) where contamination occurs

The method selected for well abandonment should be consistent with the following purposes of well abandonment:

- Prevention of groundwater and soil contamination via the well
- Prevention of intermixing of subsurface water via the well
- Conservation of hydraulic characteristics of hydrogeologic units
- Minimization of physical hazards

5.2.1 Abandonment Requiring Casing Removal

If casing removal is specified in the work plan, four methods may be considered:

- Casing Pulling
- Casing Destruction
- Overdrilling
- Overcoring

5.2.1.1 Casing Pulling

Casing may be pulled using hydraulic jacks or the lifting capabilities of the drilling rig. A vibration hammer may also be used to augment the pulling. A high viscosity bentonite drilling mud may be placed in the casing to minimize collapse of the borehole walls as the casing is pulled. After the casing has been pulled, the borehole must be reamed to a diameter larger

than the original hole to remove the annular materials in order to promote a good seal between the borehole wall and the new grout.

5.2.1.2 Casing Destruction

Destruction of the casing can be accomplished by drilling out the casing in place. Either hollow-stem auger or rotary drilling methods may be appropriate. A pilot bit or guide attached to the lead auger or tri-cone bit is advanced within the well casing as a guide in drilling out the casing. A high viscosity bentonite drilling mud may be placed in the casing and periodically added as the boring is advanced. Thorough removal of the annular grout should be undertaken, either by drilling the boring to approximately the same diameter as the original borehole, or by reaming the borehole after making the initial run to destroy the casing.

5.2.1.3 Overdrilling

For the purpose of this SOP, overdrilling refers to the use of hollow-stem augers to drill around the well casing. The hollow stem auger should have an inside diameter of at least two inches larger than the well casing, and the auger flights should be at least the same diameter as the original borehole. The augers are drilled to the full depth of the original boring. If possible, the casing will be pulled with the augers in place. If the casing should become stuck within the hollow stem, water may be forced down the casing and out the screen in an attempt to free the casing. If this procedure fails, the casing must be pulled simultaneously with the augers. Reaming will be necessary after the casing is pulled to remove any remaining annular materials and debris.

5.2.1.4 Overcoring

For the purposes of this SOP, overcoring refers to the use of drilling equipment to overcore the well casing with a core bit. The core bit should have an inside diameter at least two inches greater than the outside diameter of the well casing. The casing is overcored to its total depth, and is pulled prior to or simultaneously with the drill rods. The boring is then reamed to a diameter larger than the original hole to remove annular materials and debris.

5.2.2 Abandonment Without Casing Removal

If specified in the work plan, the well may be abandoned with the casing left in place. Wells which do not penetrate a confined hydrostratigraphic unit (HSU) may be grouted as addressed in Subsection 5.2.3. Wells penetrating more than one aquifer or contaminant zone may also be abandoned with the casing left in place. If, however, documentation of the well does not clearly indicate that the casing opposite each confining layer or between two contaminant zones has been properly grouted, or if the well is otherwise known to be nonviable due to absent or inadequate grouting, the casing in such intervals must be perforated or ripped. These intervals will require pressure grouting.

5.2.3 Grouting

Unless specified in the work plan due to site-specific conditions, grout shall consist of American Colloid Company "Pure Gold" grout, or approved equivalent, mixed according to the manufacturer's instructions. Grout will be emplaced by pumping through tremie pipe or drill stem, with the bottom end of the pipe always being maintained below the top of the grout slurry within the well. It is advantageous to begin the grouting process with hollow-stem augers or temporary casing in the borehole, removing sections as the grouting progresses in order to minimize borehole collapse. Grout should be applied in as nearly as continuous a procedure

from bottom to top as is practical to minimize segregation, dilution and bridging problems. If possible, the tremie pipe should be kept near the bottom of the well, and the grouting continued until it is purged from the borehole undiluted.

To abandon wells in HSUs with high permeability, clean sand may be placed by tremie pipe up to the static water level (in unconfined HSUs) or to the confining layer (in confined HSUs). A seal of hydrated bentonite will be placed above the sand. After allowing sufficient time for the hydration of the bentonite seal, the well will be grouted to the surface as described above.

5.2.4

Surface Protection

If casing is left in place, a water-tight cover must be permanently fixed to the top of the casing. Remaining casing may be cut off a minimum of one foot below ground level provided the permanent cover is attached and original surface contours are restored.

For all wells, concrete will be placed above the top of the bentonite grout, after allowing sufficient time for the grout to set. This concrete should extend three to five feet below the ground surface. At the surface, the concrete will consist of a slab, shaped within a concrete form at least six inches thick (vertical dimension), with a diameter no less than two feet greater than the diameter of the well. The form should be dug slightly into the ground so that the surface of the finished concrete slab will be one or two inches above the ground surface. Welded wire fabric (10-gauge or heavier 6-inch x 6-inch) shall be placed at mid-depth in the slab.

When the concrete slab is semi-hard, a stainless steel or aluminum plate with well ID and date of abandonment will be anchored to the surface of the slab. The date on which abandonment of the well was completed will also be written in the surface of the concrete while semi-hard.

6.0 EQUIPMENT DECONTAMINATION

Pertinent decontamination procedures described in SOP 1.3, General Equipment Decontamination, and SOP 1.4, Heavy Equipment Decontamination, will be followed. Decontamination and wash water will be handled according to SOP 1.7, Handling of Decontamination Water and Wash Water.

7.0 HANDLING AND STORAGE OF MATERIALS

The materials removed as part of the well abandonment process will include:

- Large solids (e.g., lengths of semi-intact well casing)
- Small solids (e.g., drill cuttings, old grout, destroyed well casing)
- Liquids (e.g., drilling fluids, excess grout and formation water)

The following describes the methods which will be followed to handle and store these materials.

7.1 CASING

Casing will be cut into manageable lengths as it is removed from the borehole. The casing will be scanned with a radiation meter and PID. Clean the casing with a brush to remove the major dirt and debris. Wrap casing in plastic sheeting or plastic bags, tape shut, and transport to the central decontamination station. Finish decontaminating casing using a high pressure hot water washer. Stack into piles on plastic tarp. Cover with another plastic tarp. EG&G personnel will then screen the casing and determine the appropriate method of disposal.

7.2 SMALL SOLIDS AND SEMI-SOLIDS

These materials (e.g., small pieces of casing, concrete, drill cuttings, etc.) will be handled according to SOP 1.8, Handling of Drilling Fluids and Cuttings.

7.3 LIQUIDS

Liquids displaced from the borehole during grouting will be collected and handled according to SOP 1.5, Handling of Purge and Development Water, and SOP 1.8, Handling of Drilling Fluids and Cuttings. This will require provision at the ground surface to collect fluid, such as a portable "keyhole" pit or berm around the top of the borehole or casing discharging to a tank. In deep boreholes when relatively large quantities of fluids are anticipated, more elaborate measures such as grading the area and constructing lined pits, may be required to control displaced wastes. This will be addressed in an SOPA.

8.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) activities will be accomplished according to applicable project plans as well as quality requirements presented in this SOP.

9.0 DOCUMENTATION

Information required by this SOP will be documented on the Well Lugging and Abandonment Form (Form 3.11A), and Drilling Field Activity Daily Log or logbook. Waste handling will be documented according to SOP 1.8, Handling of Drilling Fluids and Cuttings. The information will be recorded in a logbook.

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- Project, crew and borehole identifications
- Weather conditions
- Equipment descriptions (rig, tremie, pump, etc.)
- Water level in borehole prior to abandonment (if any)
- Borehole depth/diameter
- Volume of grout placed
- Type/length/diameter of casing/screen removed
- Type/depth/diameter of casing/screen left in place
- End-of-day status (i.e., partially complete, cap set, etc.)
- Chronological record of activities

Copies of the completed Well Abandonment Forms, together with a cover letter signed by the task manager and field geologist, will be mailed within 30 days of the abandonment to:

Colorado Division of Water Resources
Office of the State Board of Engineers
1313 Sherman Street, Room 818
Denver, Colorado 80203
ATTN: Well Abandonment

WELL PLUGGING AND ABANDONMENT FORM

1. Well Specifics:
- a. Well Id. No.
 - b. Reported well depth (feet)
 - c. Field well depth (feet)
 - d. Number of screens
 - e. Screened interval(s)
 - f. Screen diameter(s)
 - g. Screen type(s) (SS or PVC, etc.)
 - h. Casing diameter(s) (in.)
 - i. Casing type (PVC, steel, etc.)
 - j. Stickup or flush mount
 - k. Penetrates confining layer(s) (Y or N)
 - l. Aquifer(s) monitored

2. Reason for Abandonment:

3. Abandonment Specifics:
- a. Date abandonment begins
 - b. Date abandonment ends
 - c. ID number of field book used
 - d. Site personnel
 - e. Drilling method used
 - f. Grout used
 - g. Casing removed (Y or N)
 - h. Metal detection plate installed (Y or N)
 - i. Concrete pad inscription

- j. Briefly describe abandonment method:

- k. Disposition of materials removed from well:

4. Comments or problems encountered:

Name, title and company of person
completing this form

Signature and Date

Attach one copy of Well Abandonment Log to this form when completed. Attach one copy of the Well Construction Log (if available) to this form when completed.